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IONOSPHERIC PULSE TRANSMISSION
OVER LARGE DISTANCES:
IDENTIFICATION OF TRACES

by

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Germany

I O N O S P H E R I C   P U L S E   T R A N S M I S S I O N

O V E R   L A R G E   D I S T A N C E S :

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In the present situation working on contract AF 61(052)-129 we have got a certain number of delay time records over the transatlantic path whilst the number of usable amplitude records is yet small. As the identification of the traces is very difficult from amplitude records alone it was assumed that the main interest of a general survey in this moment is to give the rules for identification obtained from delay time records.

This is done in the following report where we try to give these rules first in a rather general form and explain them finally by some examples which are discussed in detail. When introducing scientific workers to the interpretation of oblique incidence pulse records we have always found that is difficult at the beginning to identify correctly the different traces. The reasoning which is necessary for this sort of work is not straight forward but in some way complex as different conditions must be satisfied at the same time. Fortunately man's intellect is working in such a way that this sort of complex reasoning is done automatically if enough experience has been obtained. So training plays a very important rôle for this sort of work. We hope that the following pages may be helpful for training purposes in the frame work of the project.

A. EXPERIMENTAL SITUATION

a) State of affairs.

Since the last annual report another pulse transmission line has been established between Breisach(Germany) and Elevsis near Athens(Greece). The receiving station in Greece has been established by our personnel; after instruction it is now operated by the observatory of Athens under separate contract (Professor Anastassiades). According to the smaller distance this line is mostly operated with frequencies between 10 and 13 MHz.

The total network is now:

two communications (different frequencies)

Breisach – Plum Island(Mass) 5846 km

one communication

Breisach – Elevsis 1709 km

The frequencies used were 16,638 and 12,62 Mhz for the transatlantic circuit and 12,62 and 11,040 Mhz for the greek circuit.

The first distance is too large for one hop communication, it is a "large distance". The second one is an "intermediate distance", one hop communication is regularly observed. The interest to have an intermediate distance is for intercomparison. On behalf of the ocean we could not have a western receiving station at intermediate distance from Breisach on the transatlantic orbit itself. Therefore the control distance has been chosen as an eastward prolongation viz. Breisach – Elevsis. It is just long enough to be rather near to the limit of one hop propagation via E.

b) Technical situation

The receiving synchronizing and recording units have been described earlier (see annual summary report no 1). The three equipments are all similar with the exception that one cristal clock is used for both receiving sets at Plum Island. The station at Elevsis is at the same place with a virtual sounding ionospheric station; therefore it was necessary to synchronise the sounding unit with our recurrence frequency.

One major technical difficulty has been encountered: the synchronization was not so good as it could be excepted according to the indications given by the manufacturers of quartz cristals. When beginning we had a long

experience with a serie of non-thermostated quartzes, these had a rather good accuracy as they were cut quite well. At that time we had been working with higher recording speed than now so that the quality needed for usable records was about $2 \cdot 10^{-5}$. When changing over to the new thermostated cristals we went over to a higher recording speed as the promised accuracy was much better, at least 10^{-6}. Unfortunately the thermostates delivered with the new cristals are not good enough to hold this accuracy, or the cutting angle was not accurate enough. At any case the new cristals when regularly readjusted (once a day) and with a constant room temperature come to an accuracy of $4 \cdot 10^{-6}$ which is just sufficient with our present recording speed. But when the cristals are not regularly readjusted or the room temperature is not kept constant the accuracy is not better than with the old, non-thermostated cristals.

During the last months the Plum Island station was under continuous control by Mr. Büchau and from that time we have rather usable records. The Elevsis station did not yet reach the same quality because of the known difficulties of the starting period.

c) Sample records

a) Delay time records

Some sample records of magnetically quiet days are shown in the Figs. 1 through 5; Figs.1 through 3 are from the transatlantic circuit, 4 and 5 from the Greek circuit. We show here only delay time records obtained by luminosity control of the c.r.tube. Amplitude recordings are also made but these shall be discussed in another report when more results are available.

As the interpretation of Figs.1 through 3 is given in detail in part C we shall only say here that the main echoes are

$2F$, $3F$, $4F$, $2F + E$ and , probably, $2F + 2E$.

b) Backscatter records

In order to control the efficiency of our transmission and also to have an indication of the ionospheric conditions on the eastern part of the Atlantic we regularly receive at Breisach the backscatter echoes from the trans- mitters working for the transatlantic circuits. Figs.6 through 9 give some selected samples. Most of these are peculiar cases where the fluctuations were extremely large. Normally the records are less spectacular.

In these records the time goes from left to right, distance

downwards. The very sharp echoes appearing in daytime e.g. in Fig.6 are vertical incidence echoes. The backscatter traces are normally broad, between i and 2 msec. The skip distance is sometimes very well marked as the upper margin of such a trace, sometimes it is not defined at all. Large scattering surfaces appear in some of the records, up to 4 msec.

It seems to us if most of these phenomena were due to deformations of the F-region, in particular the transitorial disturbances which go through the region from top to bottom in about 5 min. Typical sequences can be seen in Fig. 8 and, in particular in Fig. 3. In these cases, of course, an instantaneous determination of the skip distance from the zone of highest luminosity would be extremely misleading.

B.   REDUCTION OF DELAY TIME RECORDS

1. General principles, explained with short distance transmission.

Reduction of oblique incidence records requires some experience. It is not
too difficult if one has a clear idea of the phenomena happening at
oblique incidence which are in some respects different from those at
vertical incidence. Systematic observations of pulses at oblique incidence
have first been made by Crone, Krüger, Goubau and Zenneck[1] in 1935/36.
These authors used a telephone cable for synchronization of their stations
which were distant by 560 km. At each end of the line they had a trans-
mitter and a receiver; therefore they could use a special system of reduction
which has been developed by Goubau and was improved later by Eyfrig[2]. We
begin our explanation with the description of this method because it gives
a clearer understanding of what must be done in the case of the device used
in our present experiments as in most experiments of this sort, viz. trans-
mission from one endpoint only.

a) Travel time and virtual height (transmission at both endpoints)
Fig. 10 gives an example of records obtained simultaneously at Kochel and
Berlin. The echo traces are essentially horizontal, this is due to the
special system of synchronization used in these experiments. (With our
"free floating" synchronization technique the echoe traces are slowly
changing their position with time so that they appear inclined on the film.)
Both transmitters were keyed in a different way so that the corresponding
traces could easily be distinguished; in our figure the transmitter at
Berlin was interrupted in the middle of the reproduced time period whilst
the Kochel transmitter was interrupted at the beginning and at the end.

The reduction method used is independant on the special synchronization
system, it uses only the reciprocity of the delay time in both directions.
So by combination of the observed instant of pulse reception at both ends the
unknown travel time of the waves between both endpoints, A, B, can be
determined.

Be t_1 the time of pulse transmission in A and t_{12} the time when the
corresponding signal is observed at B, then the travel time of the signal is

$$(1) \qquad \tau = t_{12} - t_1$$

In the same way we have for the transmission at B the instant t_2 and the
corresponding reception time at A is t_{21}; the travel time of this signal

is therefore

(2) $$\mathcal{T} = t_{21} - t_2$$

If we look at Fig.10 we can obtain from the record obtained at station A the time difference $\mathcal{T}_1$ between the arrival of the signal coming from B, t_{21}, and the transmission of the next signal at station A itself, t_1, therefore

(3) $$\mathcal{T}_1 = t_{21} - t_1$$

can be read from the record. In the same way the corresponding time difference

(4) $$\mathcal{T}_2 = t_{12} - t_2$$

can be obtained from the records at station B. With these four equations one obtains

(5) $$\mathcal{T}_1 + \mathcal{T}_2 = 2\mathcal{T}$$

So in a device with transmission and reception at both endpoints the travel time of the echoes can be determined directly.

It can now be used to determine the apparent path of the waves. For this calculation the refracting influence of the ionospheric layers is described by a simplified model with reflecting mirrors instead of the refracting ionospheric layers. Of course these model mirrors must be assumed to lay at greater altitude than is the true reflection height of the waves. Therefore we introduce a virtual reflection height which is that height where the mirror must be placed in order to give the observed travel time. (This virtual height at oblique incidence is not identic with that observed on the same frequency at vertical incidence; Martyn[3] has given an approximate relation to find that frequency which at vertical incidence gives the same virtual height.) If we neglect first the influence of the curvature of the earth and consider the case of the first echo we have the conditions explained in Fig.11. Fig.11a gives the conditions for short distance transmission by one hop reflected from the F region, Fig.11b is for the case of reflection from the E layer, As the distance ,d, of both endpoints is known we obtain from Fig.11 the following relation for the virtual height h' (valid for one hop transmission)

(6) $$h' = \sqrt{(\tfrac{1}{2}s)^2 - (\tfrac{1}{2}d)^2} = \tfrac{1}{2}\sqrt{s^2 - d^2}$$

s is the virtual transmission path of the ionospheric wave, it is obtained from $\mathcal{T}$ with the vacuum velocity of the light, c ,

(7) $$s = c \cdot \tau$$

For the given distance, d, of the experiment the relation between s and h' can now be plotted; for d = 560 km we have Fig.12. Not all values of the virtual height are effectively obtained, with reflections from the F region virtual height values between 180 and 500 km are possible, but most records give heights between 200 and 400 km. As to the E reflection the possible height range is much smaller, varying between about 80 and 130 km. Note that Fig. 12 does not take account of the curvature of the earth, so it is only a first order approximation.

It can be seen from Fig.12 that for a reflecting layer at low altitude the height does not much influence the wave path, i.e. the travel time is nearly the same as for a ray traveling along the earth. For the identification of E-echoes it is therefore not important to determine the reflection height precisely, it is sufficient to use h' = 110 km as an approximate value. As to the F region it can be seen from Fig.12 that the height variations are more efficient for the travel time and also the range of possible values is much larger; therefore it is necessary at the identification of echoes to determine the virtual height of the F echoes numerically. For this aim a graph like Fig.12 but taking account of the curvature effect is used. This, besides is the first aid which must be produced before an identification of oblique incidence records can be made.

For the two hop way ($2 \cdot F$ or $2 \cdot E$, broken lines in fig.11)a similar curve can easily be obtained. In the general case with curvature one first calculates the corresponding relation for the half distance, 1/2 d, but when plotting the s value so obtained is multiplied by 2. So the broken curve in Fig.12 has been obtained. In a similar way with the relation calculated for the distance d/n and multiplication of s by n when plotting, the relation for n hop transmission is found.

b) Travel time and virtual height (transmission at one end only).

We have of course supposed that the virtual reflection height was the same for all reflection points occuring with multiple echoes. This assumption is not always true and just for very large distances we must be aware that variations of h' are inevitable. If on the other hand we admit this assumption our problem is over determined when we have observed more than one echo. In fact instead of using transmission on both sides and determining τ by intercomparison we can also determine the effective virtual height from

Fig.12 when only the difference in travel time between the first and second
hop echo is known.

This is now the method how the unknown effective virtual height can be
determined in those cases where only one transmitting station is used. It is
quite clear from our deduction that with this device it is not possible to
determine h' when only one echo is present. But as the first interest of
reduction is the identification of the different traces one can even use
periods with only one trace if before or after several traces are present
on the record.

It might be useful to explain this procedure with some example. In
Fig.13 we have plotted two traces corresponding to 1 ' F and 2 'F recorded
during the old experiments over 560 km. The ordinate of this record is the
travel time given at the left side, the corresponding path length is given
on the right hand scale. At the beginning of these records the time difference
between both echoes was 1.7 msec this corresponds by equation (7) to 510 km.
We can now use Fig.12 looking for conditions where the (horizontal) difference
between the one hop and two hop trace has the right value viz. 510 km; this
is valid for an h' value of 305 km and this is the effective virtual height
which must be used in this case. If there were differences in the virtual
heights of the three reflection points which we consider this procedure
remains correct provided that the average of the reflection height is the
same for the two hop path and for the one hop path i.e. in the case of
linear variation of h' with distance. Only if this variation cannot be appro-
ximated by a linear function our procedure becomes less accurate. If we bear
in mind that the virtual height found by our procedure is only a represen-
tative average value over the distance there is no difficulty with most
records to obtain the correct identification of the traces by this method.

For the application of our procedure it is easier to plot directly
the difference of the s values. instead of using Fig.12; this has been done
in Fig.14 where (always neglecting the curvature) the difference of ray path
between the two hop and one hop echo is represented as a function of the
effective virtual height, h' (axis are inverted with respect to Fig.12).
With a diagram of this sort the effective virtual height can be determined
very quickly if multiple echoes are present.

c) Complicated echo paths

We have not yet mentioned that complicated multiple echoes can exist and
we should say what must be done with these. At short distances the echoes

which are mainly observed are (Fig.15)

          1·E,   2·E,   3·E
          1·F,   2·F,   3·F,   4·F,   5·F
          E+F,   2E+F, E+2F
          M ,   M2 ,   M3

The multiple echoes of the third line are simply obtained by combining some hops reflected by the F region with some other reflected by the E region; this occurs rather frequently when Es is present. The calculation of the corresponding diagrams is some more complicated than for the more normal transmission paths , it is based on the condition that with or without curvature if only the ionosphere is horizontal the angle of ray incidence at the different reflection points on the ground for a given path must be the same everywhere. This is explained in more detail in the following chapter. Similar reasonings must be made for the intermediate paths which travel in the space between the E and the F region by successive reflections (fourth line). The M echo is most known, it is obtained with one intermediate reflection from the top side of an ionized layer in the E region, normally Es. The corresponding way with two reflections on this top side shall be designated by M2, etc.

It may be interesting to give an example for the statistical distribution of different propagation paths on a short distance. Fig.16 obtained at a distance of 650 km gives results obtained in summer and winter respectively on a frequency which is rather well adapted to this distance [4]. It can be seen that the communication is good in daytime in winter but not in summer, and that the contrary is true for nighttime. The statistics of the different transmission paths is very different in summer and in winter als also between day and night. During summer days we had practically complete blanketing so that no F paths existed; the only usable path was that reflected by E. In winter daytime blanketing was not efficient as the critical frequency of the E layer was lower and the first and second F path were frequently observed; 3F was only observed in the morning and evening, near noon this path was strongly attenuated by normal absorption. During the night absorption is not important and the multiple F paths play an important rôle. The probability of communication via E depends on the occurence of sporadic E; this is also valid for the probability of the mixed path E + F which comes to more than 30% of probability in summer evening.

d) Special phenomena

People familiar with vertical incidence ionograms know the behaviour of echo traces near a critical frequency. The phenomena observed at oblique incidence are somewhat different and must be discussed here. It may first be observed that the phenomenon corresponding to an approach to the critical frequency at vertical incidence is an approach to the MUF at oblique incidence; as for a given distance different transmission paths have different MUF values it is clear that we observe these phenomena at different frequencies in the case of a variable frequency device or at different times if one uses a fixed frequency. So the different multiple transmission paths are no more a simple repetition of the first order as in the case of vertical incidence.

As a consequence of the geometry the differences in virtual height are less efficient at oblique incidence; therefore the path difference between the o and x component of the magneto-ionic theory is less pronounced at oblique than at vertical incidence. This is a first remark which is useful for the interpretation of oblique incidence records. Normally the difference between o and x trace is only apparent in the neighbourhood of the MUF condition or for higher multiples which occur only at night when absorption is small.

Another remark concerns the retardation cusp which at normal incidence is seen near a critical frequency. This cusp does not occur in the same form at oblique incidence because we have the complicated ray geometry [5] as demonstrated in Fig.17. We indicate in this figure how the rays coming at different angles from a transmitter are refracted in the iono-sphere. Flatrays are bending in a way as if they were reflected in the lower part of the ionosphere, therefore they come to ground at large distances. With increasing elevation angle we come to a ray(No.2 in Fig.17) which may just arrive at our receiver at the distance d . We see, however, that there is another steeper ray (No.4) which arrives at the same point but under another elevation angle; this ray is curved when entering the ionosphere and travels for a longer way in the highly ionized part of the layer. This is the so called Pedersen ray [6].The existence of this ray has the consequence that the geometrical optics of the ionosphere is ambiguous in a certain sense. There exists a limiting ray with an angle between that of No.2 and No.4 for which both rays fall together; this is at the same time that ray which comes to the shortest distance, the so called "skip distance". No smaller distance can be attained by rays refracted in the ionosphere. Therefore the definition of the MUF (maximal usable frequency) is given by the falling together of the

Pedersen ray with the normal ray. Steeper rays (like No.5) are Pedersen rays which come to larger distances. However, all Pedersen rays together cover only a small range of the possible elevation angles. Rays which are again steeper (No.6) penetrate the layer with a large lateral deviation; with increasing angle the refraction effect becomes now smaller so that we have finally rays penetrating the ionosphere at steep incidence without a remarkable refraction effect (No.7).

The most essential result of this discussion for ionospheric one hop transmission is the existence of in principle two possible rays between the transmitter and the receiver. This gives two delay times, that of Pedersen ray being normally much larger than that of the normal ray. It must also be stated that with the small angular range from which Pedersen rays are originating the energy transmitted by Pedersen rays is rather small if the distance is much larger than the skip distance , d_{min} (Fig.17). Therefore the Pedersen ray is well marked only near the MUF condition and the MUF condition is given by the going together of both rays. This can be seen from Fig.18 which shows a splitting up of the o and x component for the normal reflection path just before the MUF condition for the ordinary ray is reached. At the point designated by o the Pedersen ray comes together with the normal ray and the one hop ordinary component transmission stops at that point. The arrow-like form of the trace is characteristic, it is also called a "nose". After that time the ionization decreases more and more and at the point designated by x the normal ray and the Pedersen ray of the x component combine. This is the MUF condition for the x-ray. By chance, in Fig.18 we see at that place a phenomenon which has more importance at larger distances; this is the so called "nose extension" which is especially important when spread echoes play a rôle.

If the ionospheric layer is stratified it must be treated as an assembly of two layers and if further the maximum electron density is not very different in both of these we can observe a combination of two arrow forms which gives a characteristic Z-form. This occurs especially in the case of transiterial layers which disturb the F-region for a short period. As the life time of such transiteria is of the order of 5 minutes it occurs rather frequently that the Z-form is only visible for one of both magneto-ionic components. For example in Fig.19 we have a Z-form for the extraordinary ray but the ordinary ray which came to the MUF condition about 10 minutes earlier shows quite a normal arrow form. It can also occur that by a transi-terial disturbance the effective electron density is increased for a short

It is not very useful to make a reduction only in the form of a numerotation of different paths simply following the observed order. This would yet be dangerous if we had only multiple hop ways reflected from the F region; as this is not so and with increasing distance we have more and more intermediate paths serious errors can occur when the identification of the paths is not made correctly at the reduction of records. It seems to us that some reductions which did not take account of identification following the rules indicated here are more or less worthless for scientific use.

a) Ray path and angle of incidence

Always under the assumption that the curved path can be replaced by a reflected virtual path the geometry of the different paths can easily be obtained, even for complicated echoes, if the relations, for incurved earth and ionosphere, between angle of elevation, virtual height and ray path are known. This calculation can be made by pure geometry[7]; another solution is possible with a large scale drawing like that reproduced (with a considerable decrease of scale) in Fig.21. From this diagram which takes fully account of the curvature the relations can be obtained mechanically.

As an example we give in Figs.22 - 27 curves obtained by Gonnermann[8] for the 6400 km distance Berlin - NewYork. Figs. 22 - 24 give the ray path (ordinate) as a function of the virtual height (abscissa). The normal multiple paths reflected from the F region are given in all three figures. In Fig.22 the relation valid for the mixed way with one more hop reflected from the E region is additionally given, in Fig.23 the corresponding path with two hops reflected from E and in Fig. 24 the combination with the M path.

Fig.25 - 27 give the corresponding diagram for the elevation angle (measured between the ray and the horizon) and the virtual height (abscissa). The difference between the different paths which where pretty clear for short distances are less and less clear for large distances if one takes account of combined reflection path. This is the most outstanding difficulty at the identification of paths at large distance transmissions.

b) Identification diagrams for large distances

It is useful for large distance records to have well adapted diagrams as a help for identification. A set of such diagrams is given in Figs.28 and 29. These have been calculated recently for the distance Breisach - Plum Island (Mass.) (5846 km).

The diagrams give the difference with respect to a certain way for the main path of multiple hop F-region transmission. As in our experience the elevation angle of the rays is not measured we have only given the difference in ray path. Both figures are valid for multiple hop paths reflected from the F region. The difference refers to 2F in Fig.28 but to 3F in Fig.29. (1F cannot be observed on this distance).

The procedure for the interpretation of a record is in principle the following: One first looks at a serie of several days of records noting those periods where several well distinct echoes are present and where the ionospheric conditions were homogeneous on the circuit. For these cases with diagrams like Fig.28 and 29 one tries to find a reasonable identification so that the sequence is well explained with an average virtual height value. By trial and error one can see what is the identification of the main echo trace which is then persecuted into those periods were only one trace is present. Care must be taken on Pederson rays which are very variable but which can be identified with some experience.

This procedure will later be explained in detail by some examples.

c) Low angle paths

If sporadic E layers occur at an appropriate place of the orbit some mixed paths can occur which have rather low elevation angles. The appearence of such traces can become very confusing if one does not realize that they are mixed and not main paths. The diagrams for some mixed paths are given in Fig. 33. Fig.33a gives delay differences with respect to the main path 2·F whilst Fig.33b gives the differences with respect to the main path 3·F.

In Fig.33a we have curves for the mixed paths (F+E) and M. (F+E) as well as M give traces which are below 2·F, the difference for (F+E) can become as large as 200 km. But that between M and 2·F is so small that it is often difficult to distinguish both. So it is easier to distinguish (F+E) from 2·F than M. In our Fig.33a we have also indicated the elevation angle corresponding to our simplified geometrical construction; both paths (F+E) as well as M are obtained with small elevation angles.

In Fig.33b we give indications corresponding to (2F+E) and to (2F+2E) compared with 3F. Here also the mixed path trace lies below the main path 3·F but, of course, above the trace of the first main path 2·F. Therefore it is easier to identify these mixed paths; it is only sometimes difficult to decide whether a trace is one or the other. In section C 2 we give an example where these paths have been found.

d) Pedersen rays

Whilst Pedersen rays are a typical feature for ionospheric oblique incidence transmission they have for a long time been considered as useless at all for radio transmission. A long time ago one of us has made a theoretical calculation based on refraction in a thick layer [9]; from this calculations it could be seen that with one hop transmission of the Pedersen ray very large distances can be obtained under suitable conditions. We showed that this propagation mode could occassionally be useful up to 5000 km. A later calculation [10] showed that the fieldstrength conditions for Pedersen rays were not as bad as had been supposed earlier. From the viewpoint of geometrical optics the energy of Pedersen rays comes from a small angular range but is spread over a rather large range. The point is now that on the other side the Pedersen ray crosses the lower absorbing layers at a steeper angle than does the normal ray, therefore it suffers less from absorption. It is known that in recent experiments with transatlantic sweep frequency records [12] the one hop Pedersen ray has been observed, in particular during certain night hours. In these cases the corresponding trace appeared only at frequencies in the neighbourhood and above the nose-frequency of the 2F path. Therefore with our fixed frequency transmission we could expect to have the one hop Pedersen ray only when the ionization has become so small that the two hop path is no more possible. With our technique it is difficult in these cases to distinguish between a one hop Pedersen ray and an M or (F+E) path.

It is evident from ray geometry that the one hop Pedersen ray will only appear when the center of the F region lies rather high. This is another limitation. As a general rule one should say that traces which do not show nose formation and go up with increasing ionization are suspicious to be Pedersen rays. Most of the time the frequencies we used were lower than those were this special ray could be expected.

We observe Pedersen rays and the nose occur rather regularly with the main path 2F, 3F and 4F. When the ionization density is rather constant it occurs that Pedersen rays are present for hours so that their contribution to radio transmission cannot be completely neglected. Of course we have normally also the corresponding main path in all these cases and the intensity of the later is nearly always more important than that of the Pedersen ray. Nevertheless in the vicinity of the nose the Pedersen ray can be rather strong.

It is very important to identify the Pedersen rays so that they
are not confused with main paths. Normally it should be possible to find the
corresponding nose. Pedersen rays do not fit into the general scheme of delay
differences. As the delay time of a Pedersen ray depends in a critical way
on the refraction in the layer for a given Pedersen ray we have a large range
of possible delay times. Practically a Pedersen ray can have any difference
against the corresponding main path. It is therefore dangerous to confound
Pedersen rays with normal rays and introduce them into the general idendi-
fication scheme give above.

As a consequence of the critical refraction conditions the traces
of Pedersen rays have a marked tendency to be diffuse. This is another
criterion.

C. **DETAILED INSTRUCTIONS FOR IDENTIFICATION OF TRACES ON DELAY TIME RECORDS.**

1. **General**

For the following instructions we suppose that the only information available is given by an unilateral delay time record. If other reliable information on the effective reflection height is available this could be used for checking, for example when ionograms of a station in a suitable position are at hand.

a) **Principle and difficulties**

The principle of the method is to make first a provisional identification which is then checked and, eventually, corrected.

The first guess is based on general reasonings and a general survey of the records of several days. The idea is that during certain periods one should be able to observe that F region multi-hop-path which has the lowest reflection number possible. It is preferable to begin with nighttime records as in daytime mixed paths travelling partially over the E region occur rather often; at night such paths can exist but they are rare. So when we concentrate on nighttime records we have better chances to avoid mixed paths which at any case complicate the identification of traces.

Of course the choice of a suitable period of the day depends in some way on the frequency. If the frequency is rather high so that communication only exists eventually occassionally during the day then it is rare that the regular sequence of multiple F region echoes can be found and it is difficult to apply the following rules. In such a case it may be interesting to work for a short test period on a lower frequency where the multiple paths occur and can be identified. If this has been done for a few days it is normally easy to find the correct identification for the main path observed on the high frequency.

If on the other side the working frequency is rather low communication via the E region becomes so important that in day time only the higher multiples from the F region can be observed, the lower multiples being blanketed by E. Mixed paths of different forms can then occur, they can make a very complicated echo pattern, even at night. In these cases it is preferable to look first for night time period where the echo pattern looks very regular with increasing delay time differences between successive traces (see 1 c). In the past we have used these reasonings for the interpretation of records of LORAN pulse transmissions on 1.85 MHz.

b) Normal method

If the frequency is not extreme but in the middle of the possible range
of communication frequencies the following procedure can be applied:
going through many night time records one looks for cases where the pulse
communication stopped completely with a clear <u>nose trace</u>. These are cases
like Fig.1 0340 UT or Fig.3 0130 UT.

Next we must see what is the lowest reflection number for a multiple
hop path reflected by the F region at the given distance. In order to have
a provisional statement we take 3500 and 4000 km as the limiting values for
the maximum of one hop propagation via the F region; the higher the F2 layer
lies the larger is this distance. Therefore we may have a larger one hop
maximum distance in equatorial regions than at temperate latitudes.

In the case of our distance of 5846 km it is quite clear that normally
the 2F path should be the main communication way. So we first suppose that
the last communication path is 2F. Now we go from that nose point along the
recorded trace in the direction of increasing ionization. After some time
their may appear another trace with a larger delay time; if this trace also
has a clear nose we can suppose that it is the next multihop F way. This
occurs for example in Fig.1 at 0130 UT. At some distance from this second
nose point the corresponding Pedersen trace will normally be clearly separated
from the trace; now we can determine the difference in delay time between
both main ways. With a diagram like Fig.28 this difference can be used to
determine an "effective reflection height". If the value of reflection height
so obtained is reasonable i.e. if it lies between 220 and 400 km we have a
first confirmation of our provisional identification. We continue now to go
towards higher ionization looking for a point where another multiple echo
appears. On the way (at least three times an hour) we note the difference
between the two main echoes and determine the corresponding reflection
height. If intermediate paths appear in the pattern it is preferable to make
the determination of the effective reflection height so often that the main
path cann t be lost during the period where mixed paths occur.

If now finally we find a third main path we can use the three traces
present in order to check our identification. In the case of our distance
for example we identify the first three main traces with 2F, 3F and 4F; from
the difference 3F - 2F on one side and 4F - 2F on the other we have two pos-
sibilities t determine an effective reflection height with the delay time

difference diagram (Fig.28). If these values are almost equal or the height
found with the higher multiple is slightly larger than that found with the
lower multiple, in that case we can suppose that our identification was
correct. If a large difference between both values is found or if that
obtained with the higher multiples is clearly inferior to that of the lower
multiples in that case we should admit that our identification was wrong
and we should try to correct it. This is normally done by going over to the
appropriate neighbouring identification.

c) Method for well experienced workers.

There exists another way to come to an identification which is faster for
workers which enough experience in the field; it is not recommended to those
who begin with this technique. In the delay time difference diagram one first
looks for an average reflection height; at medium latitudes this is normally
between 250 and 350 km. One notes the corresponding delay time difference
between the main multi hop paths reflected at the F region. The corresponding
schedule is plotted in the height scale of the records so that it can be
compared with the pattern of traces. One looks now for cases where several
traces are visible which have approximately the delay time differences given
on the plot. For skilled workers it is mostly easy to distinguish those traces
which do not fit into this pattern and which must be identified with mixed
paths.

d) Difficulties with blanketing

It must be noted that the so-called main path must not always be present and
communication can exist on higher multiples without the lowest possible
multiple arriving. This is in particular the case when blanketing is important;
under these conditions mixed paths which are rather near to the main path can
also occur this is often very confusing. For example instead of the 2F trace
a trace E+F can occur which lies below the main (2F) path; also an M trace
may replace 2F, or the mixed path E+2F can do the same thing. An example
of interchange of 2F and E+2F is given in Fig.30; there before 00 h UT the
first path was E+2F, only after 00 h 2F appeared as a weak trace. The trace
shown on the left side of Fig.30 between 2F + E and 3F is 2F + 2E. The
continuous trace above these traces is 3F, even 4F is visible with a nose
on the left side of the record (the diffuse high trace on the right side is
the Pedersen ray coming down and joining afterwards the 3F trace. This diagram
has been taken from the record reproduced in Fig.1.

At large distances it is not necessarily so (as it is usually at medium and small distances) that blanketing of the low angle F region paths goes with the opening of some replacement path in the form of a mixed path (like in Fig.30). Blanketing can interrupt a low angle path without a replacement path appearing. An example can be seen in Fig.2 between 1730 and 19 h, a large scale reproduction is given in Fig.31. The 2F path is blanketed until 1830 it is then slowly increasing in intensity but the higher orders 3F, 4F and even 5F are always present. The disappearing of the low angle path together with the existence of high angle multiples shows that <u>blanketing</u> was the important influence.

Another influence which can cause confusion is that of the combined diagram of the transmitting and receiving antennae. Directive antennae as normally used for large distance experiments have clear minima for certain angles of elevation and this can cause an important decrease in intensity of a path which for propagation reasons alone should be strong. On a given communication one can find these angles with some experience, the amplitude of the corresponding path must be given more weight.

2. Detailed discussion of examples

We proceed now to a detailed discussion of the samples records given in Figs.1, 2 and 3.

Fig.1, a nighttime record obtained in August, gives an easy occassion to apply our normal identification method. The communication closes at 0340 h and the trace ending there is identified with 2F. The Pedersen ray is present for a rather long time. (It can be seen that this ray is very variable in delay time, therefore Pedersen rays should not be used for delay time calculations.) The 3F path is seen to have its nose at about 0140 h; this is a very long nose lasting from 0100 to 0140 h. Before 01 h the Pedersen ray is seperated from the normal 3°F trace. The 2°F trace clearly appears only at 0030, it is very weak before. This is probably due to blanketing, we observe two mixed paths 2F+E and 2F+2E which are indicated in Fig.30 and have been discussed under C 1 d. The 2°F path is not present on the left side of the records; at this side the mixed path 2F+E is the first one The 3°F path is always present until 0140 h, even 4·F can be seen from 2000 through 2310; the 4F-nose is not very clear but visible, it begins at 2300 h. So in this case we cannot find a time where the first three multihop paths, 2F, 3F and 4F are simultaneously present. We determine an effective height at the earliest time when 2F is observable, i.e. at 0030. For this moment we need 410 km as the delay difference between 2F and 3F.

From Fig.28 we then find the effective height as 355 km (This is rather
high, but we have summer night conditions). The next instant to make a
determination with 3F and 4F is 23 h; for this time we find the delay
difference as 330 km, with Fig.29 this corresponds to an effective height
of 395 km. But here we are yet too near to the critical conditions. Going
back to 21 h we obtain a delay difference of 270 km and an effective height
of 350 km. This agrees reasonably with our first result.

Fig.2 is a daytime and evening record obtained in October. The
decrease of electron density for a winter evening is rather quick and so is
the disappearance of the different multiples. The communication closes
at 2110. Following the normal method (C 1 b) we may provisionally identify the
corresponding path with 2F.

Going back in time immediately we find another trace which is far
below our supposed main trace. This trace is clearly visible between 18.50 h
and 20.50 h. Another higher trace appears which is present most of the time
of the record until 2030 where it disappears in a diffuse form. According to
our supposed identification this higher trace should be 3F. The following
traces at greater height should then be 4F and 5F respectively. On the other
side we must explain the lower trace, the only possibilities we have are M
or (F+E). As the difference against our supposed 2F trace is rather large
according to Fig.33a the hypothesis must be (F+E).

The delays have been measured for three suitable hours at places of
the record where the intensity of the different traces was well comparable.
All differences are with respect to the main paths supposed to be 2F, see
Table 1, column 1. From the differences with Fig.28 we have determined the
effective height values given in the same table, columns 2. For the supposed
(F + E) trace Figs.33a (with h'E = 110 km) and 28 have been used.

Looking at table 1 we can see that there is no direct inconsistency:
the heights increase generally with increasing number of hops as it should be.
In one case this does not hold but the difference is of the order of the
reading accuracy. An argument against this identification is the very small
elevation angle necessary for the lowest trace if it is (F+E). From Fig.33a
we obtain $\frac{1}{2}^{0}$ at 1545 and 1^{0} at 1810. Such low angles are highly improbable.
Finally the absolute height values are rather great and an experienced observer
is inclined to look whether the traces cannot be explained in another way
giving smaller heights.

So we must now try another identification looking at the prede-
cessor path existing between 1840 and 2100 h. The most probable solution is
that the predecessor path corresponds to 2·F whilst the main path which we
have supposed until now to be 2·F must be 3·F. Now we have to repeat our
identifications at the different instants which we had chosen for our first
checking system. Of course we obtain the same delay differences but different
heights; both are given in the table 2. We can see that this identification
is selfconsistent. We now obtain height values which are considerably lower,
of the order of 250 km. These values are more probable than the value far
above 300 km which we had obtained with our first identification. Also the
sequence of heights obtained with the different traces increases with increa-
sing number of hops in a more homogeneous manner. Seen as an whole table 2
looks more homogeneous. Also the difficulty with the elevation angle of the
first trace exists no more now as it is identified with 2F instead of $(F+E)$;
this gives now a quite reasonable angle of elevation: 2° at 1545 and 3° at
1810. So we can state that our second identification should be right.

Now we can complete our system by looking a those places where
eventually mixed paths occur. There is a faint predecessor path which is iden-
tified with $(2F + E)$.

It is important to note that the measurement of the delay differences
should be made as accurately as possible. It is indicated for that purpose
to have a rather large scale projection so that the reading accuracy is better
than the uncertainty given by the shape of the trace itself. Normally one uses
a fixed projection enlargement so that height scales can be prepared once for
ever. These scales are obtained by graphical interpolation of the height scale
which is photographed on the film ; it is necessary for these height scales
to be sufficiently subdivided so that the reading accuracy is at least 10 km.
There is another difficulty which is due to the variable width of the traces
in particular when the traces become faint. In this case we record only the
top intensity of the corresponding pulse so that judging from the darkening
of the photographic film the trace appears to be smaller than is one of normal
intensity. Therefore one should avoid if any possible to measure delay diffe-
rences between a strong and a faint trace. It is preferable to look for
moments where the intensity is nearly equal as it has been done in the
examples. If no adequate part of the traces can be found it is necessary to
correct for the effect; long time experience will be very helpful for this
purpose.

When receivers with a differentiating audio frequency stage are used (which is normally not done in our apparatus) we have another effect which must not be overlooked. This is the effect of interference with other radio station which normally make a black vertical line on the original film, corresponding on our reproductions to a light vertical line. When a differentiating circuit is used interference of this sort increases the apparatus delay time so that the trace is shifted in the direction of retardation. This can introduce an error of more than 10 km. If the interfering station gives telegraphy in Morse the shifting effect is obtained more or less periodically so that the lower edge of the trace looses its clearness.

We consider now **Fig.3**. Here the identification is rather easy because we have a very clear nose end of the last trace at 0130 h. The corresponding trace is identified with 2F, we see that the corresponding Pedersen ray is visible for more than one hour between 2340 and 0130 h. In this particular case the interval between the main trace and the Pedersen ray is nearly filled with diffuse luminosity showing that the ionosphere was not smooth enough to give only one clear Pedersen ray on frequencies below the MUF. As the traces are repeated twice in our records we see that the lower trace visible between 1940 and 2230 h corresponds to the 2F path (because it is continuous with the trace which appears at the lower and upper edge of the film at 00 h). Therefore the other trace appearing from the beginning of the records until 2210 h must be 3F. This trace also has a clear nose frequency. A third trace is visible from the beginning of the record until 1930 h; it can be su posed to be 4F. We must now check our identification by measuring delay times, the results are given in the table 3. It can be seen that our identification is justified; the effective reflection height we obtain is again between 250 and 300 km.

There is yet one trace on the records which is difficult to explain. This is the isolated trace which appears strongly from 0240 until 0310. If this trace were 2·F we should have a nose at the opening of this path. It is not probable to be a Pedersen ray of 1·F. As the trace is followed by a diffuse follower like the 2F trace just two hours before we can suppose that it was som parenty with 2F but is a mixed path involving an Es reflection. So it could be or (F+E). It is of course not possible to check this hypothesis with one fixed frequency record only.

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Table 1 : Identification No.1 for Fig.2
(column 1 delay difference/km , column 2 corresponding height/km)

hour/UT	(F+E)- 2F		3F - 2F		4F - 2F		5F - 2F	
	1	2	1	2	1	2	1	2
1545	- 81	278	142	280	356	298	675	318
1700	- 86	288	156	303	402	320	749	338
1810	-100	310	160	308	458	345	-	-
1915	-111	328	184	330	-	-	-	-
2030	-128	350	F	F	-	-	-	-

Table 2 : Identification No.2 for Fig.2
(column 1 delay difference/km , column 2 corresponding height/km)

hour/UT	2F - 3F		4F - 3F		5F - 3F		6F - 3F	
	1	2	1	2	1	2	1	2
1545	- 81	210	142	228	356	248	675	273
1700	- 86	220	156	242	402	256	749	290
1810	-100	238	160	250	458	285	-	-
1915	-111	250	184	270	-	-	-	-
2030	-128	273	F	F	-	-	-	-

Table 3 : Identification for Fig. 3
(column 1 delay difference/km, column 2 corresponding height/km)

hour/UT	3F - 2F		4F - 3F		remarks
	1	2	1	2	
1837	-	-	294	371	
1900	-	-	373	420	
1929	-	-	393	432	Nose
1943	174	320	-	-	
2115	196	340	-	-	

Fig 1
16,64MHz 21

25.–26.8.60

00

04ʰTU

Fig. 2
16,64MHz

22.10.60

15

18

22ʰ TU
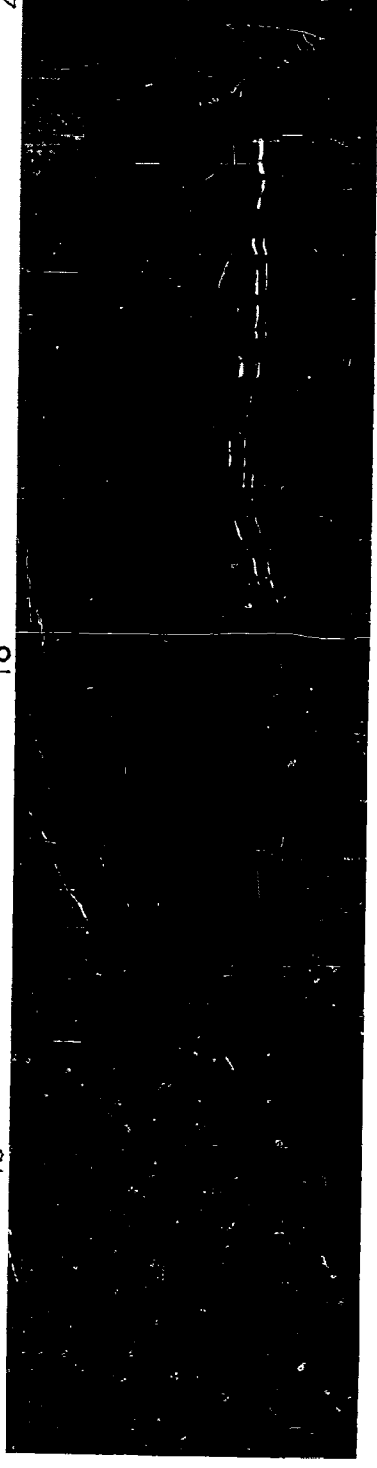
Fig. 3

19. – 20. 9. 60
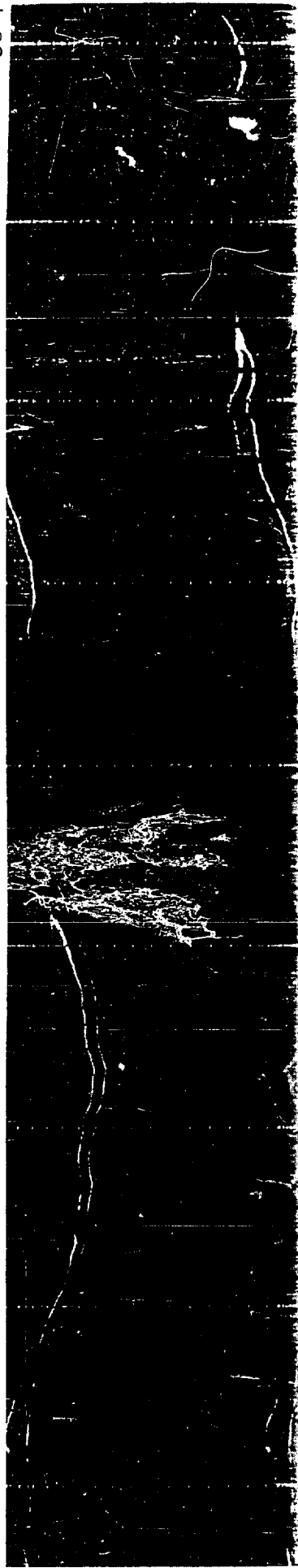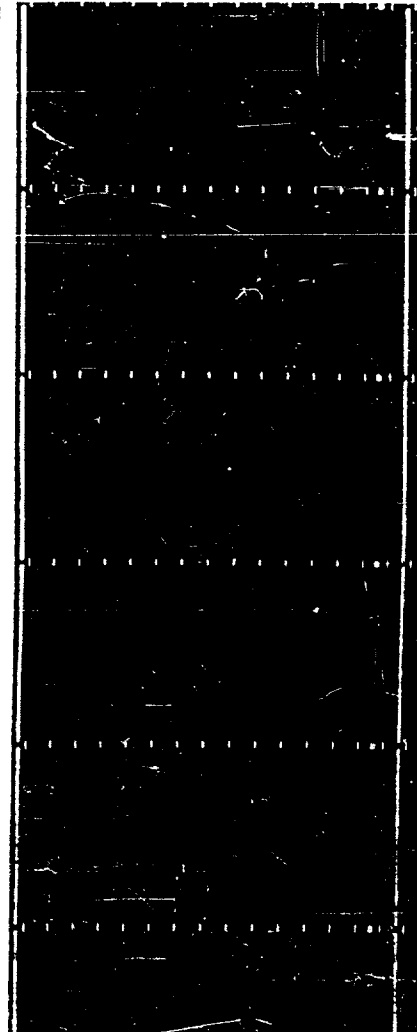
16,64 MHz   20   00   03ʰTU

Fig. 3

Fig. 5

12,62MHz   6.11.60

14   TU 17ʰ

Fig. 4

12,62 MHz   22.10.60

16   20ʰTU

Fig.6
13.-14.11.59

13 MHz

16 MHz

Fig.7
17.-18.11.59

13 MHz

16 MHz

Fig.9
14.-15.1.60.

Fig.8
7.-8.12.59

20h TU

20h TU

16

16

13 MHz

16 MHz

km σ
(2250)

2250
(4500)

km σ
(2250)

2250
(4500)

km σ
(2250)

2250
(4500)

km σ
(2250)

2250
(4500)

Fig. 10

Fig.11

Fig.12

Fig.13

Fig.14

Fig.15

Fig.16

Fig.17

Fig.18

A 19¹⁵   A 19³⁰   A 19⁴⁵

B ————————————————————————————— B

K   K

Fig.19

20⁰⁰   20¹⁵

B ————————————————————————————— B

A   A   A

Fig.20

B   B   B

B ————————————————————————————— B

16³⁰   time ⟶   K   16⁴⁵   17⁰⁰   K

Fig. 21

DIFFERENCE BETWEEN SKY-WAVE
AND GROUND-WAVE

a = distance
h = virtual height
β = angle of emission
2δ = way of sky wave

Fig. 22

Fig. 23

Fig.24

Fig.25

Fig.26

Fig. 27

Fig.2d

Fig.29

Fig. 30

Fig. 31

Fig. 32

Fig.33b
Advance versus 3F

Fig.33a
Advance versus 2F
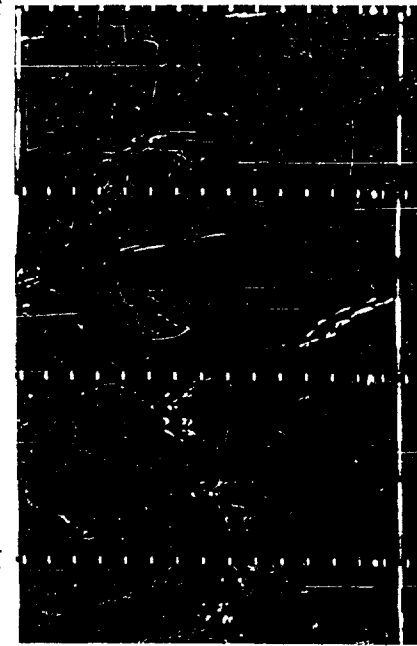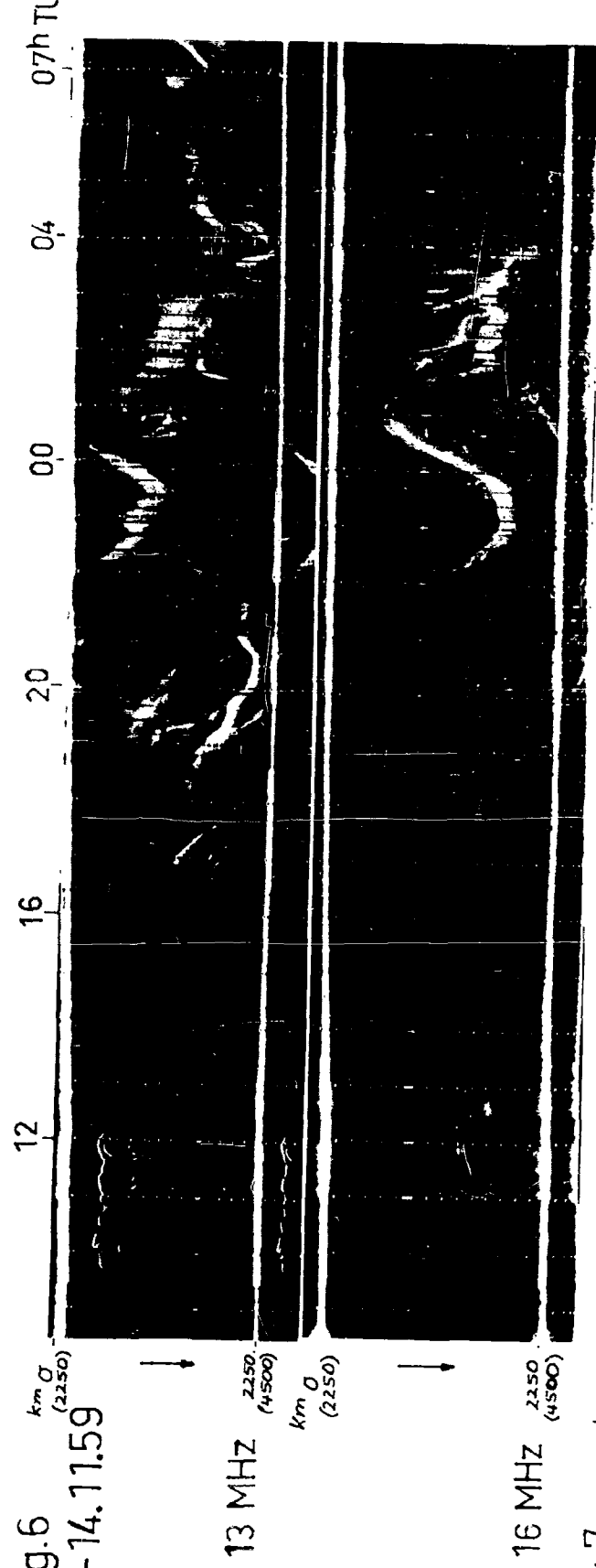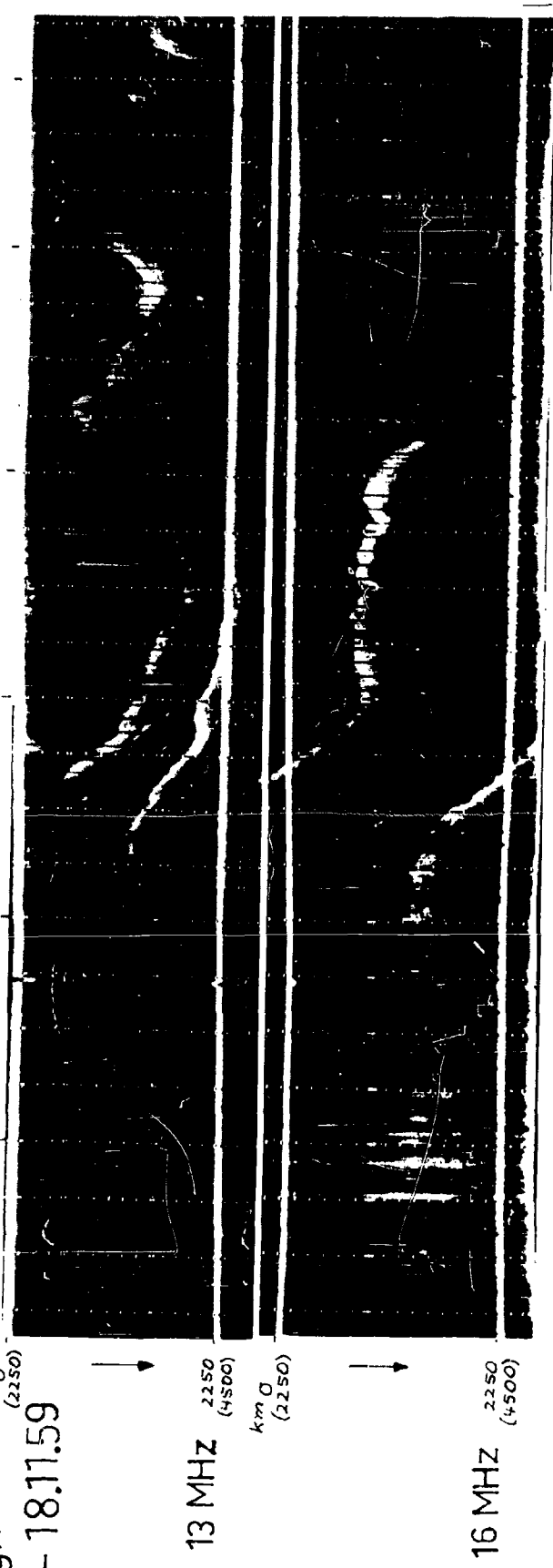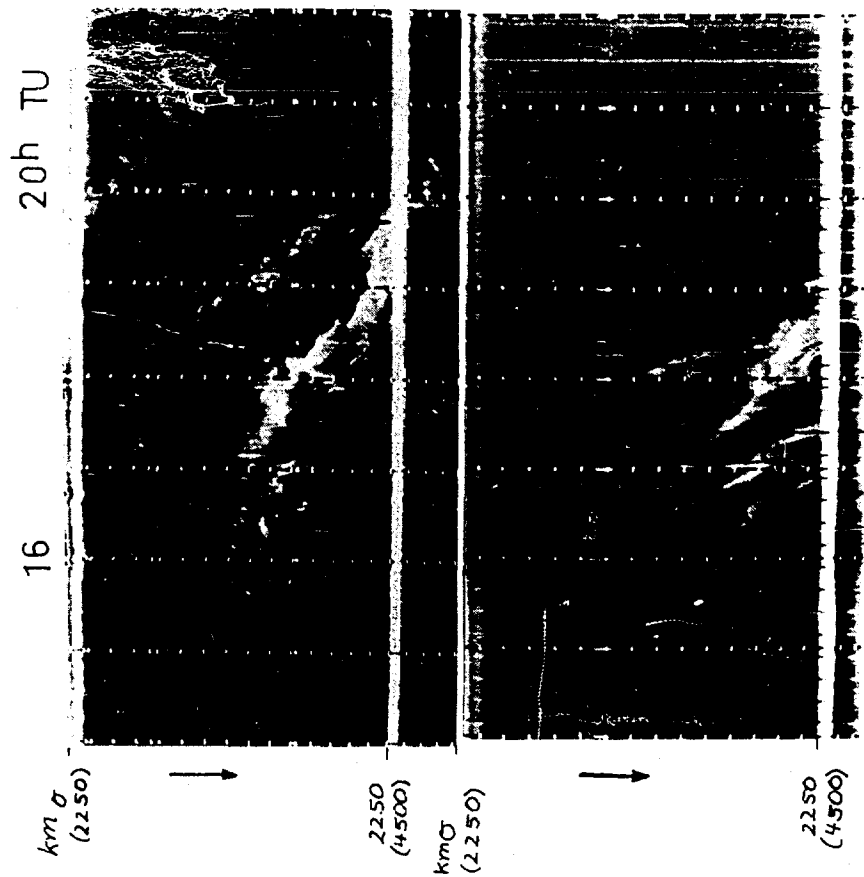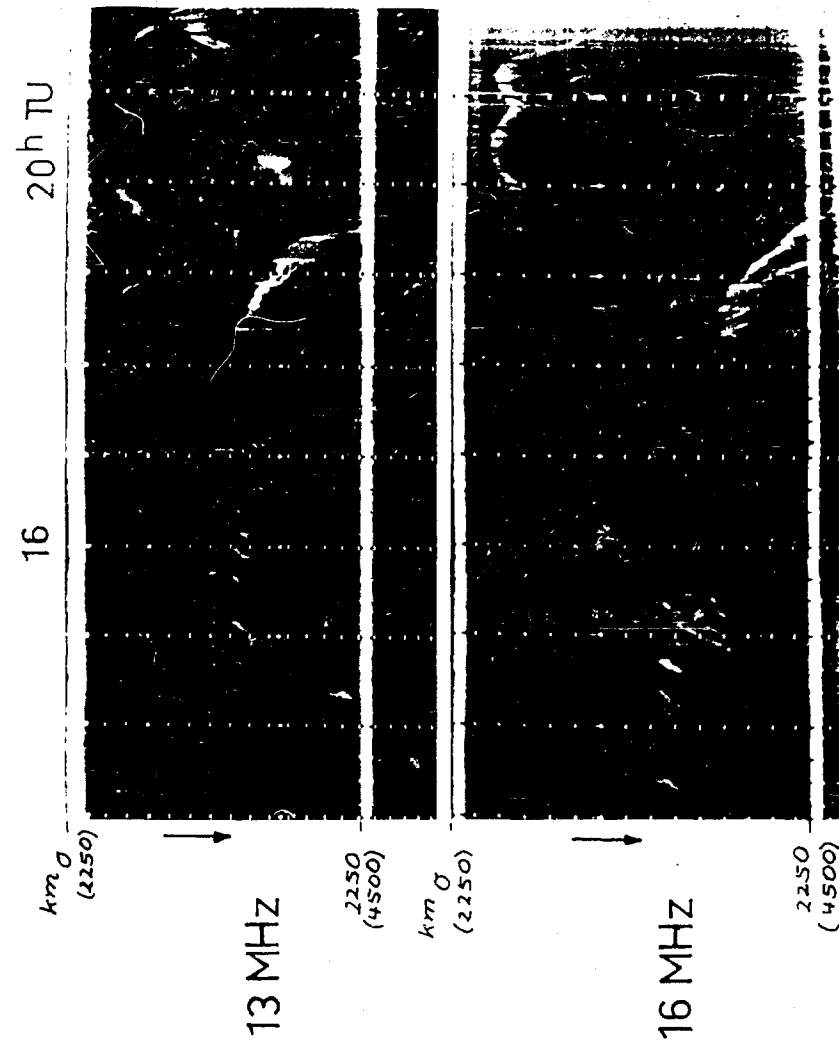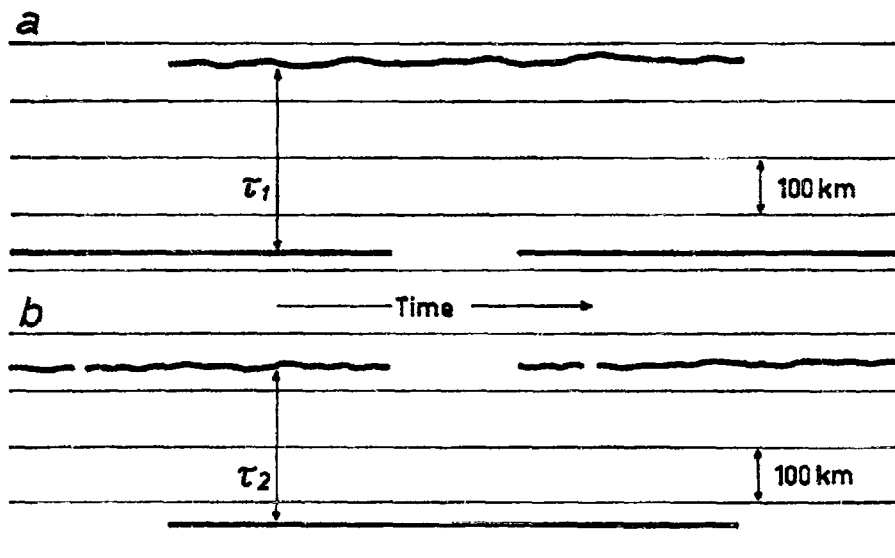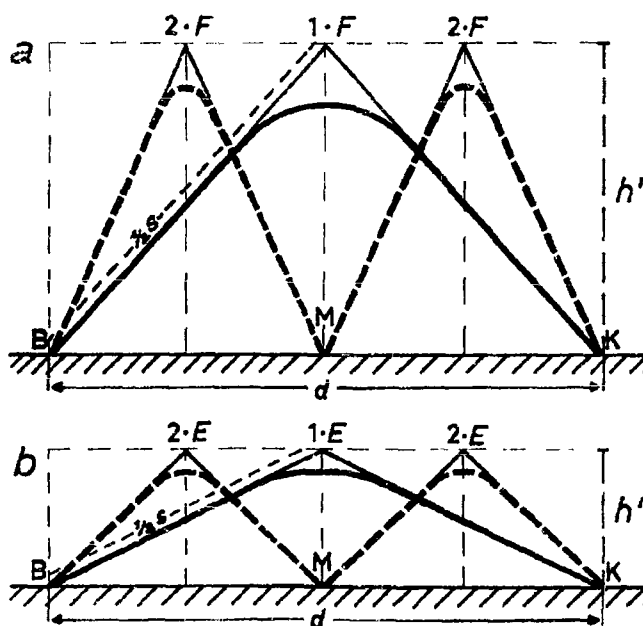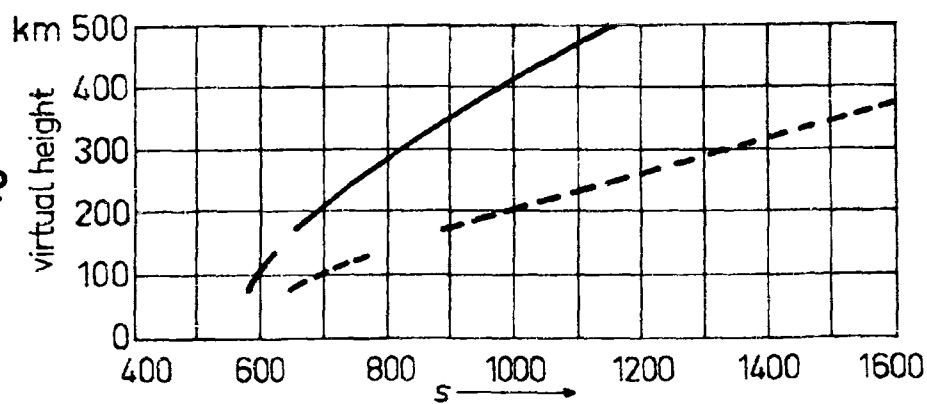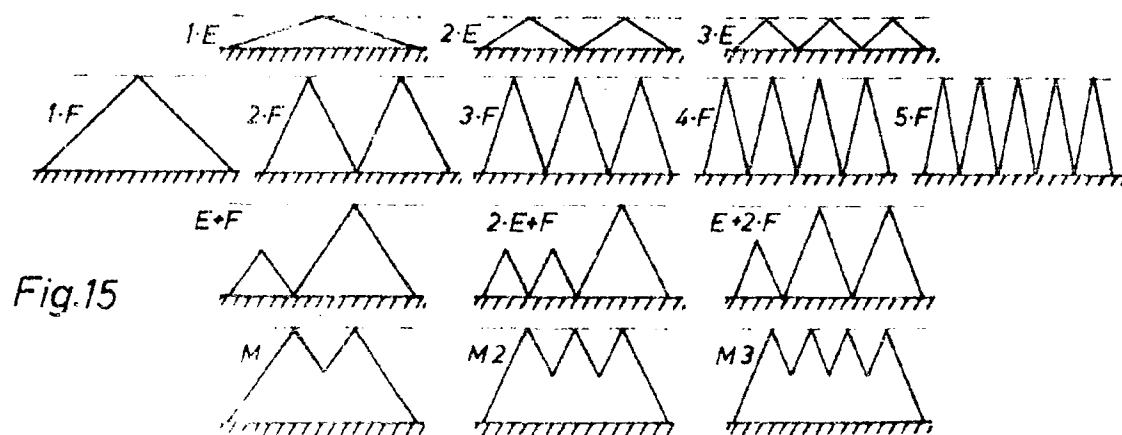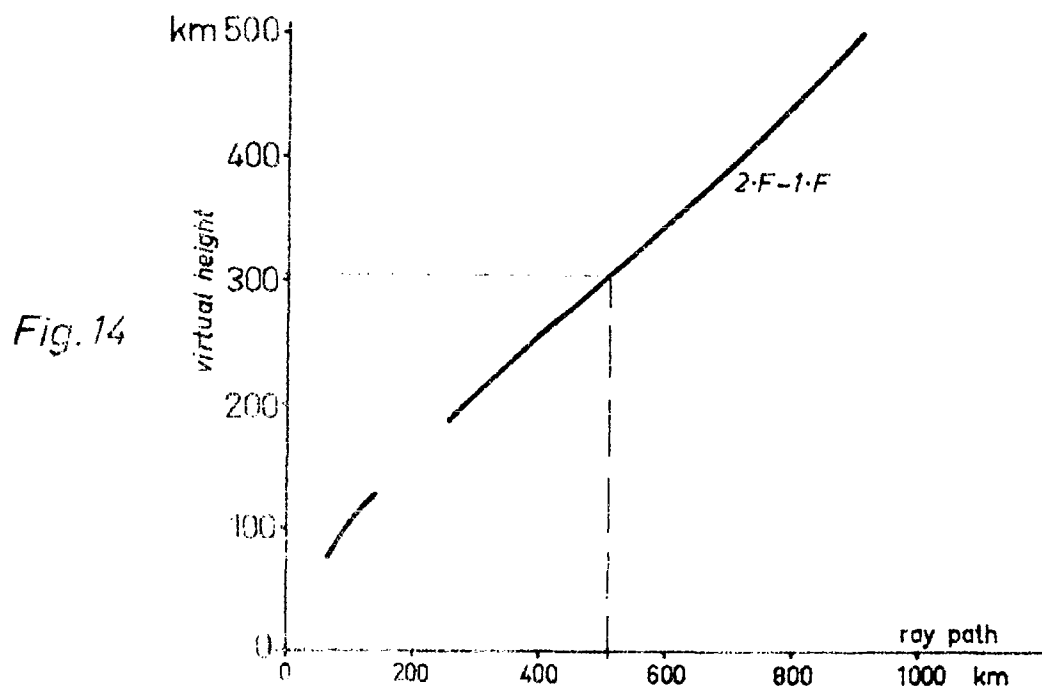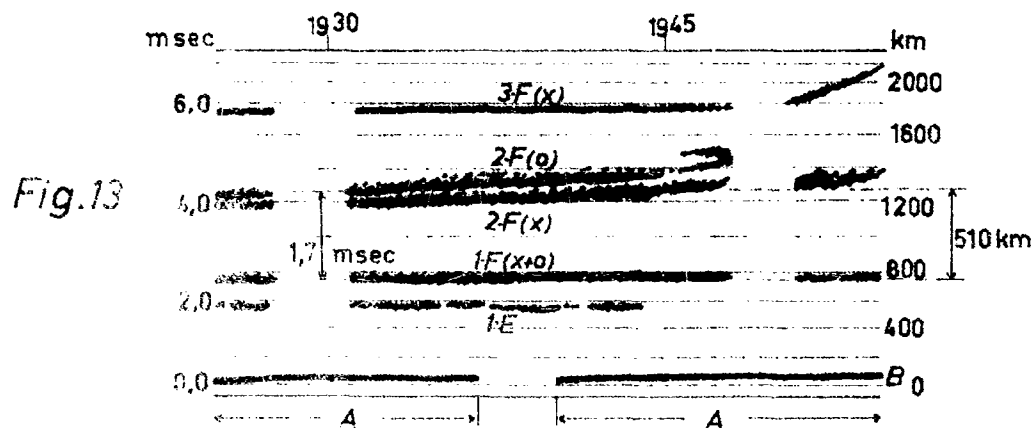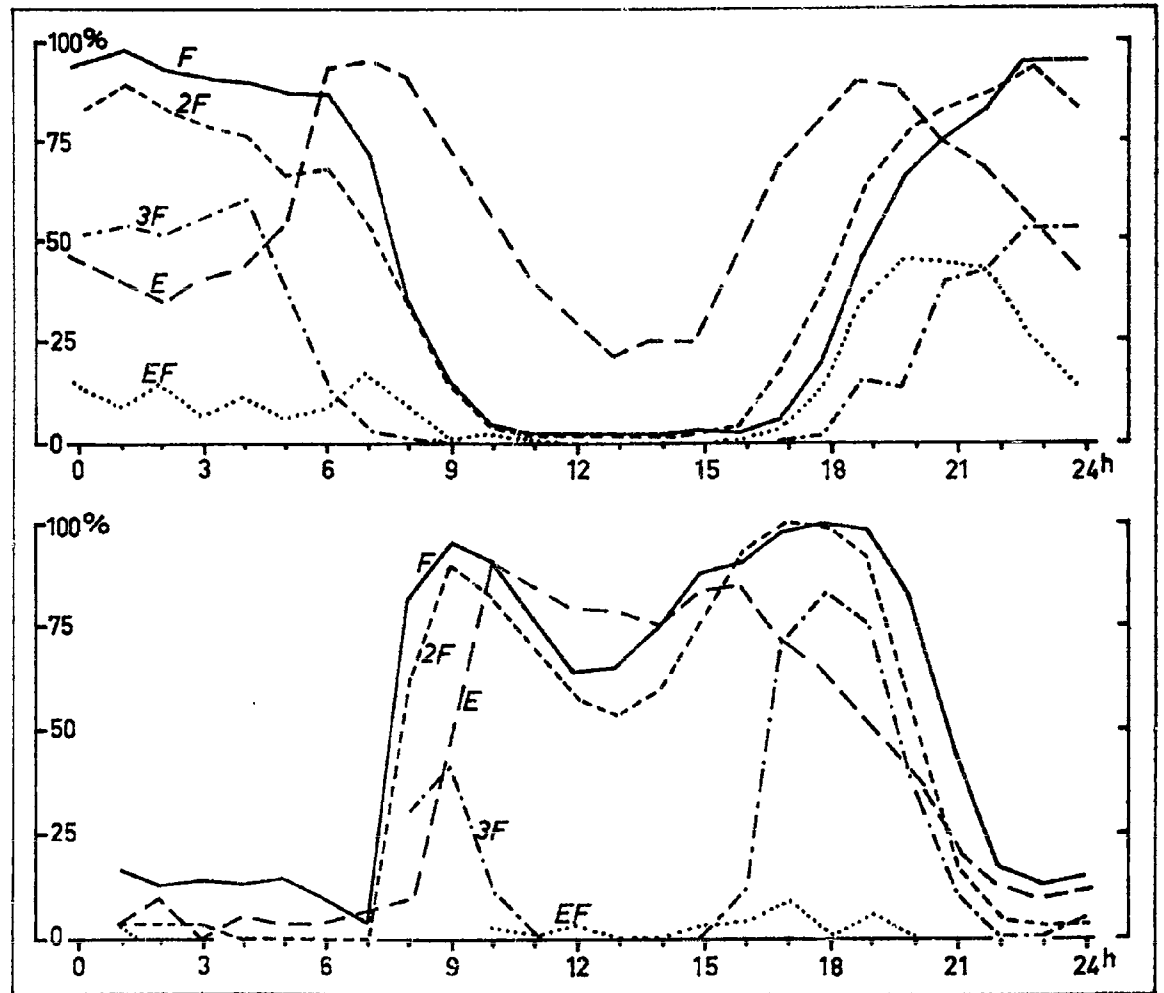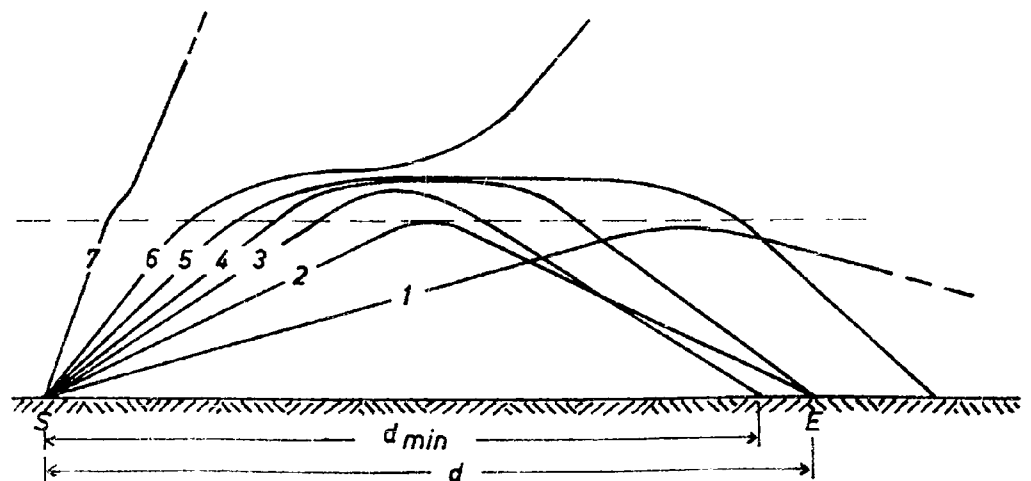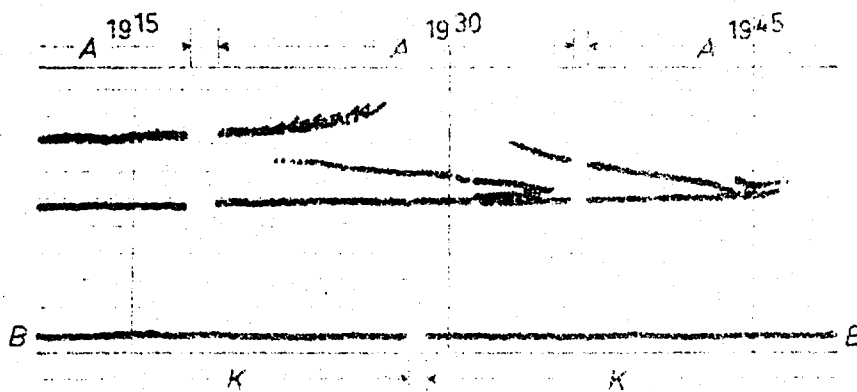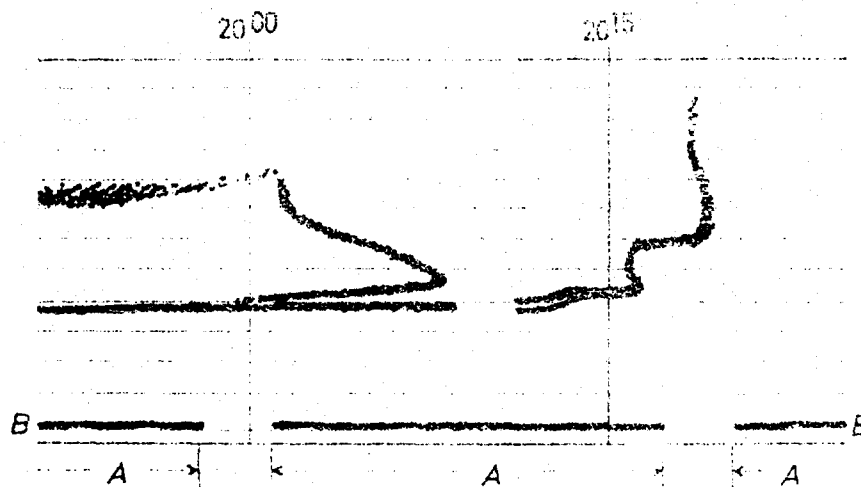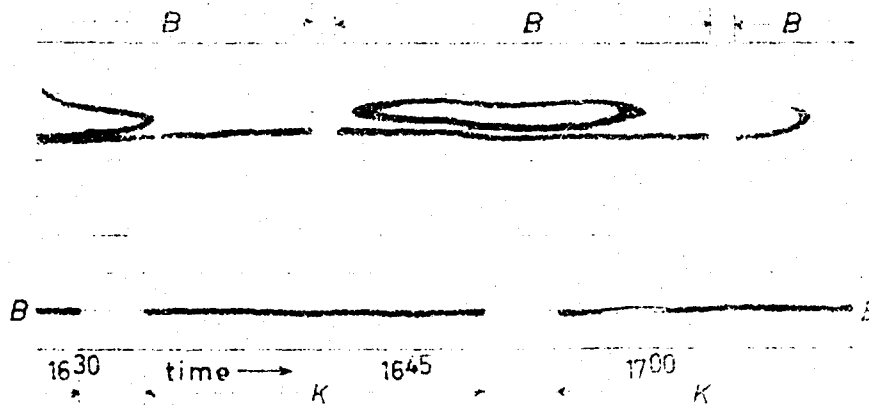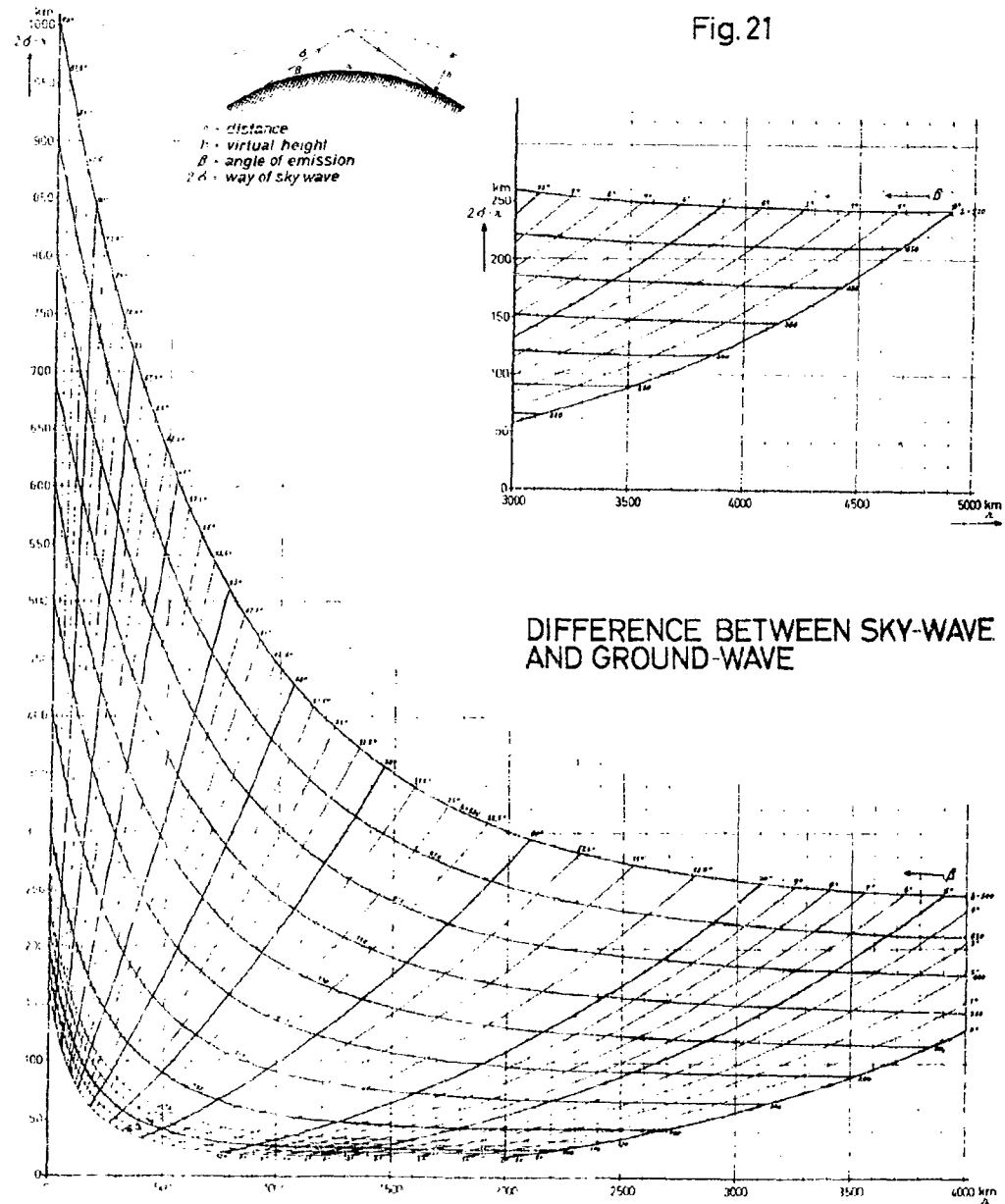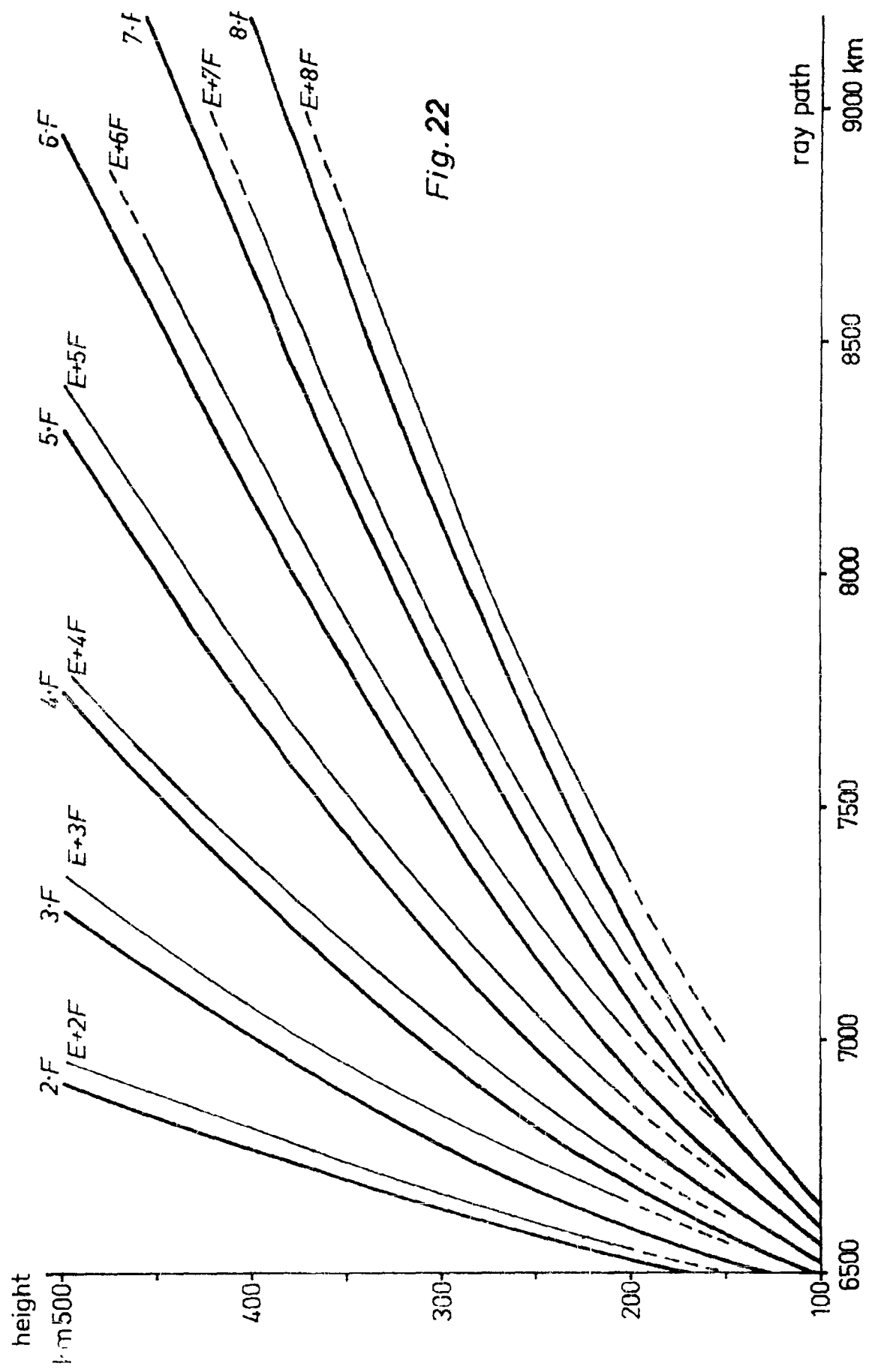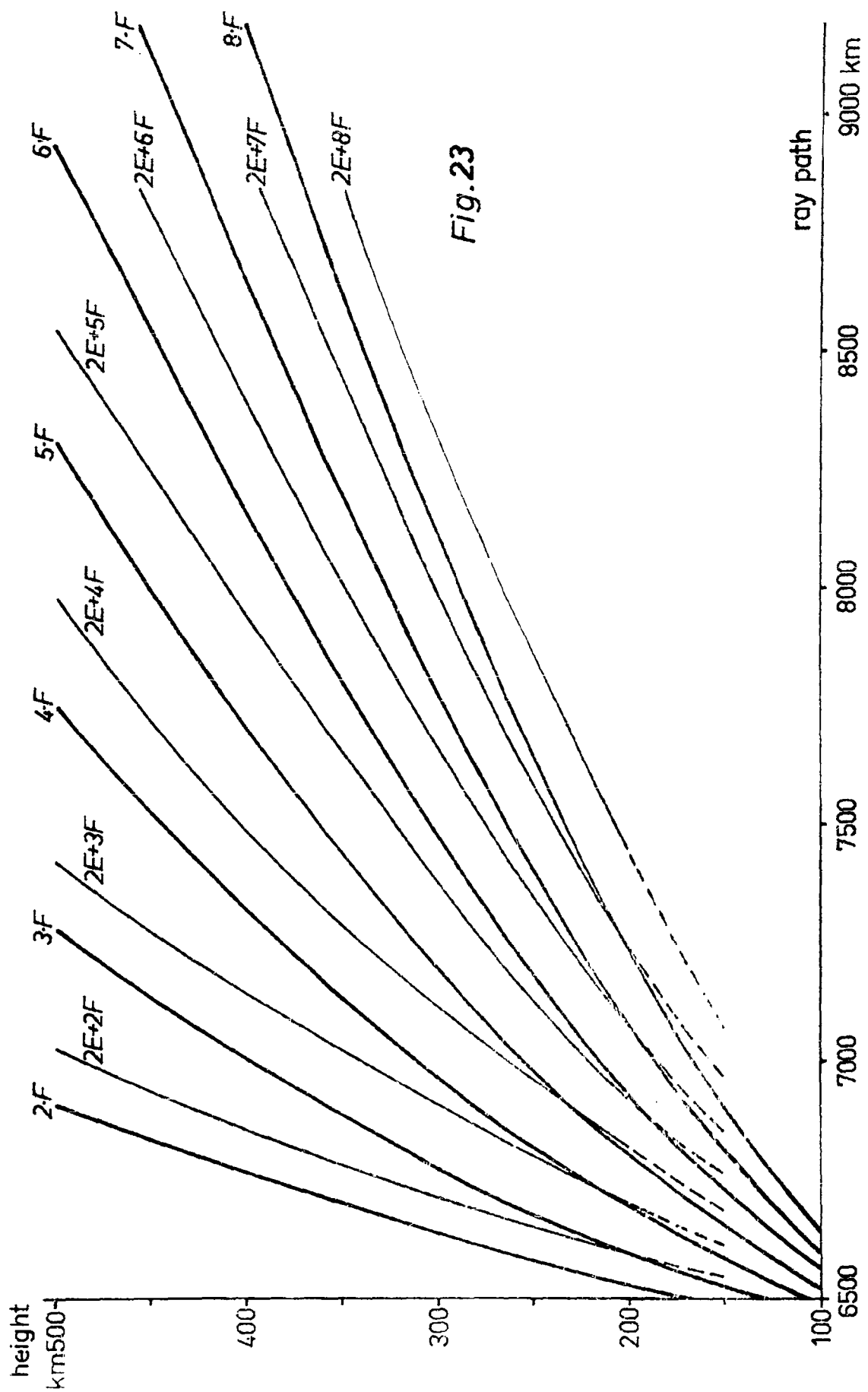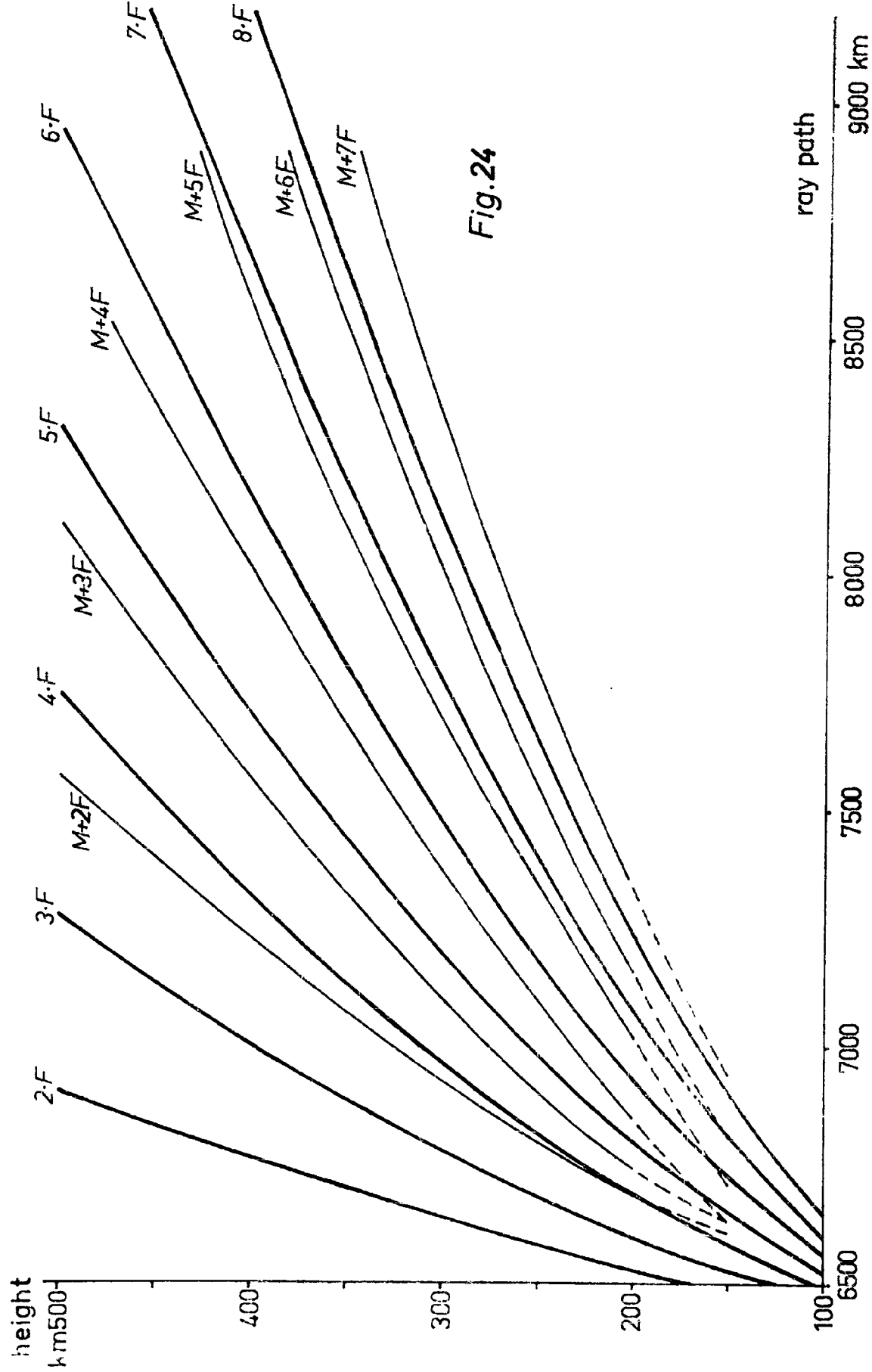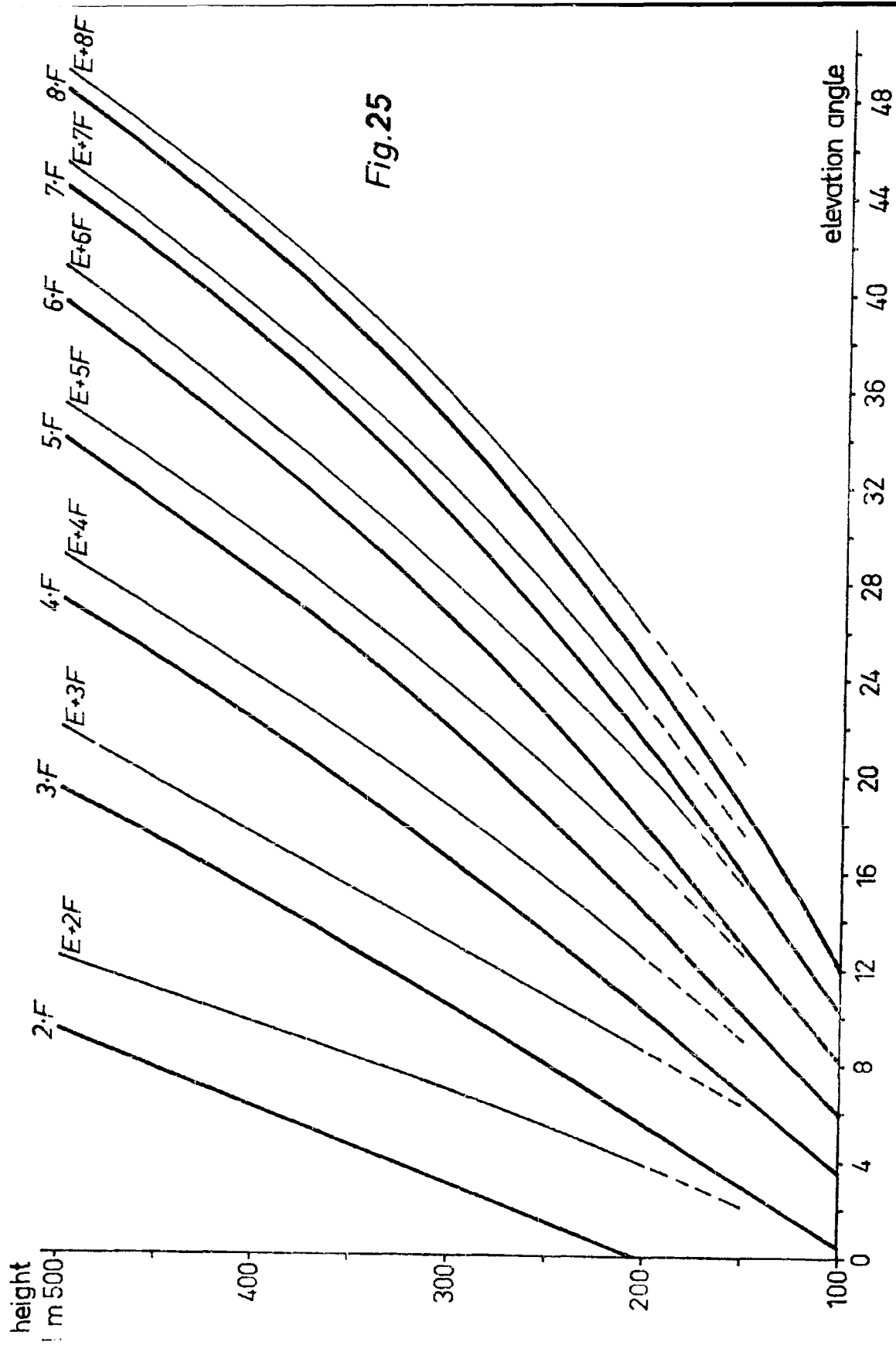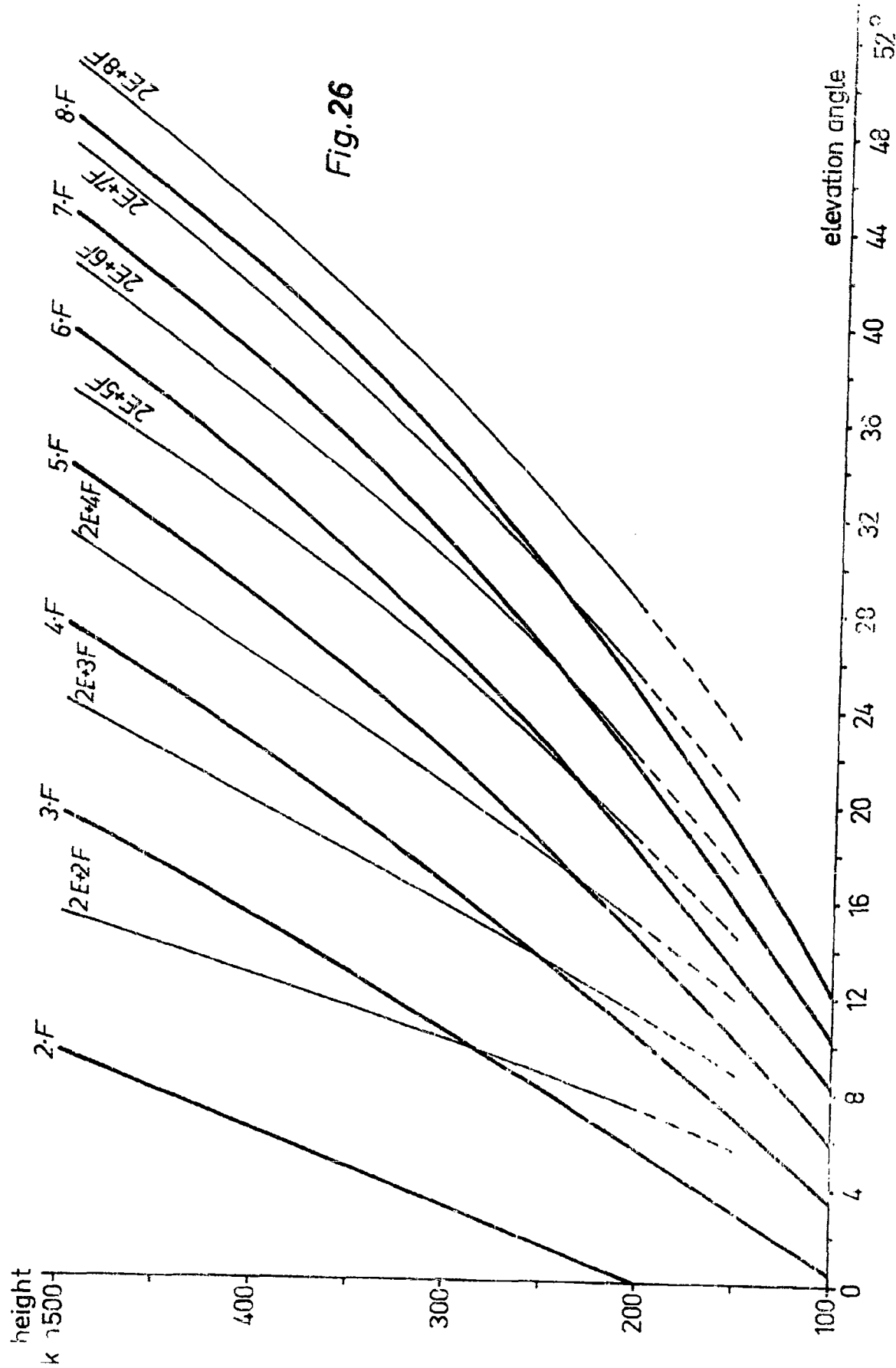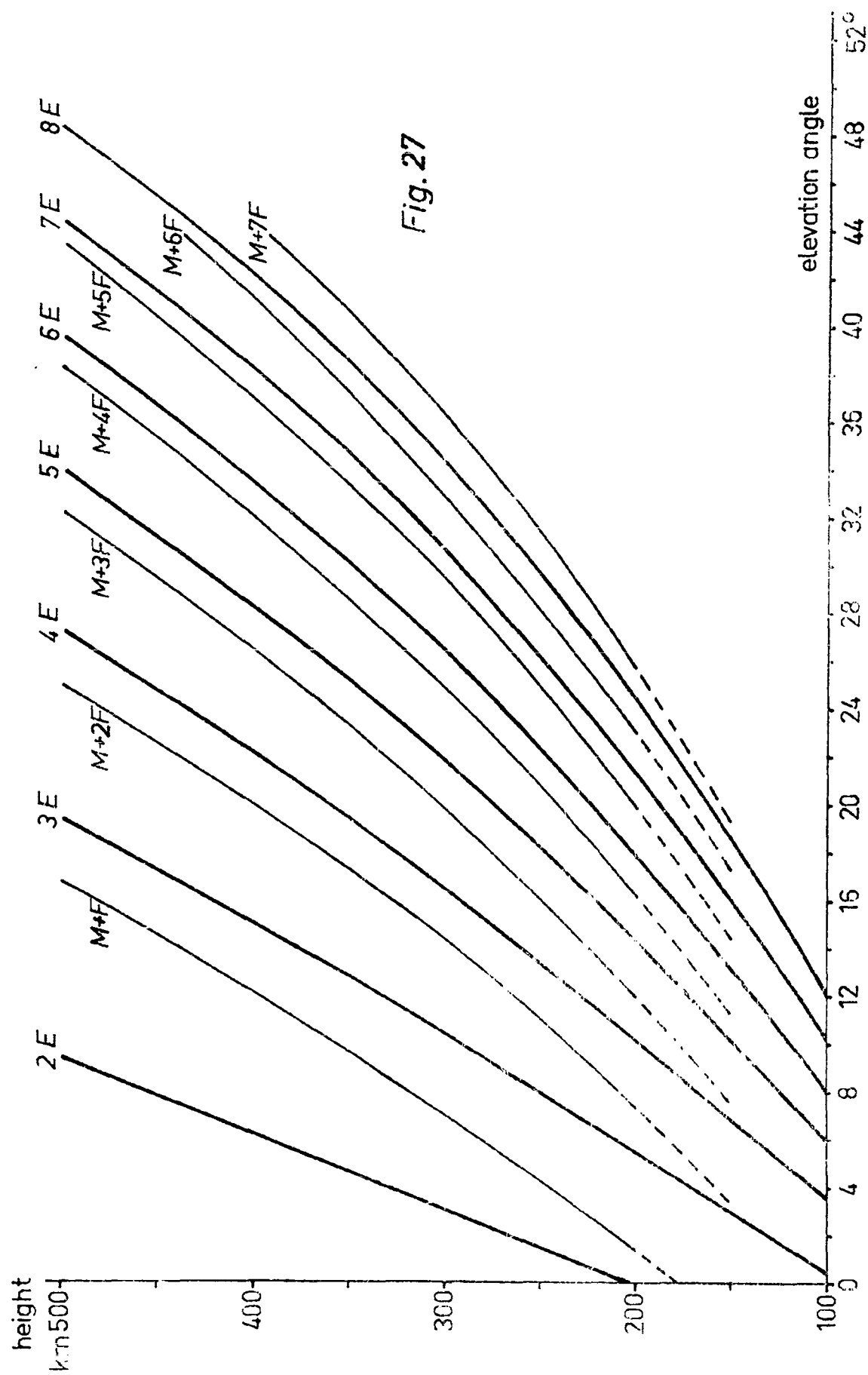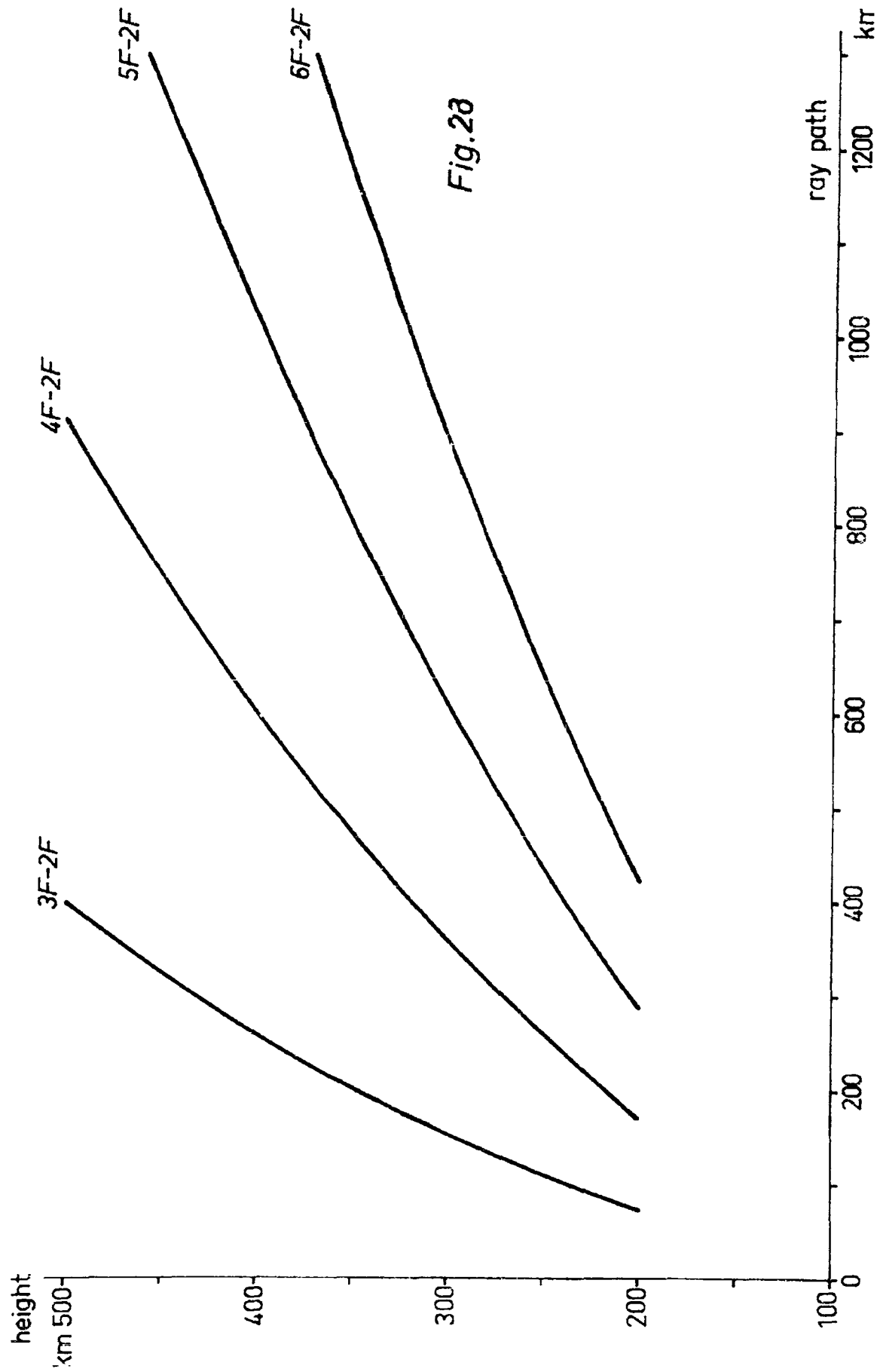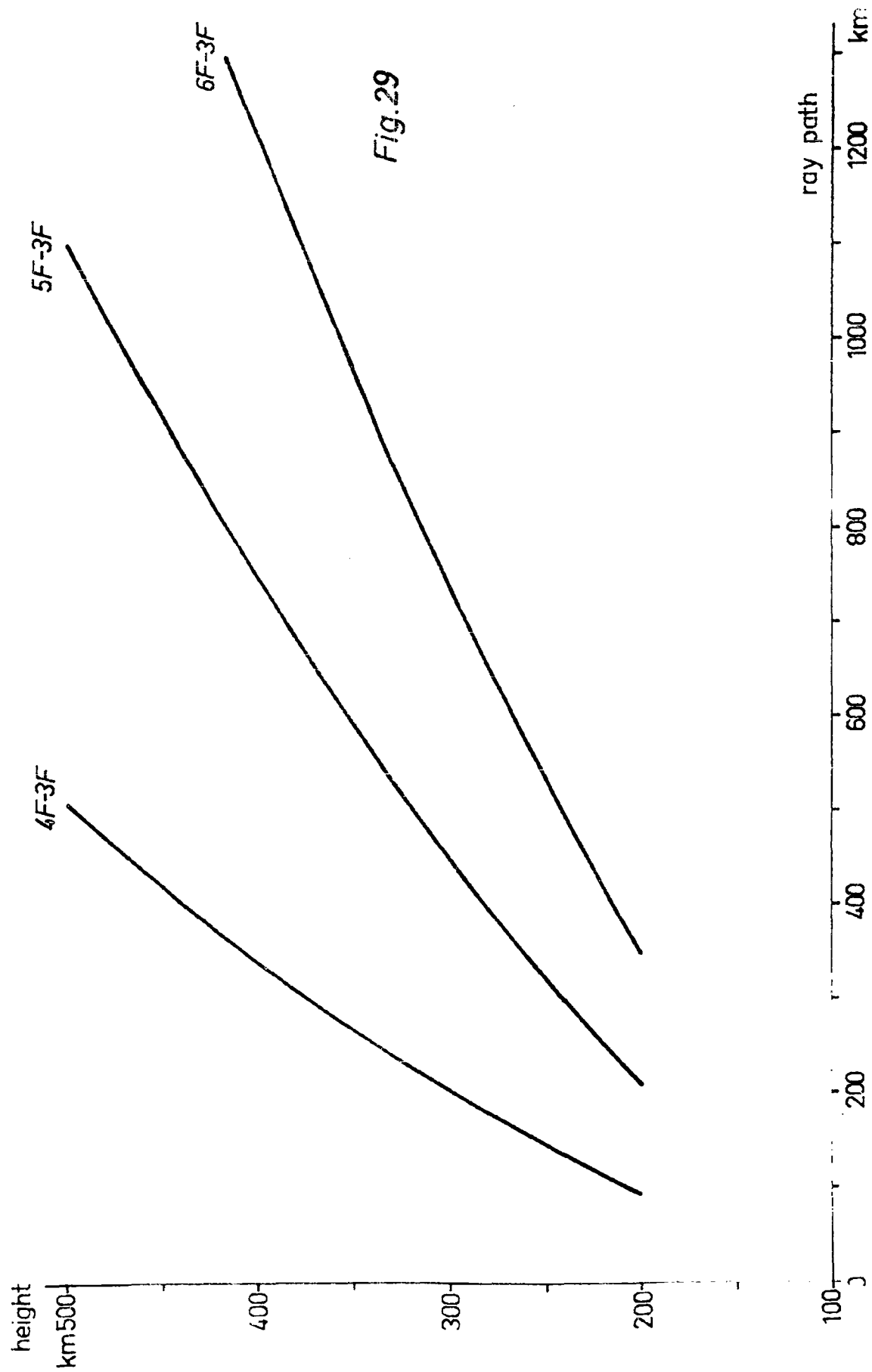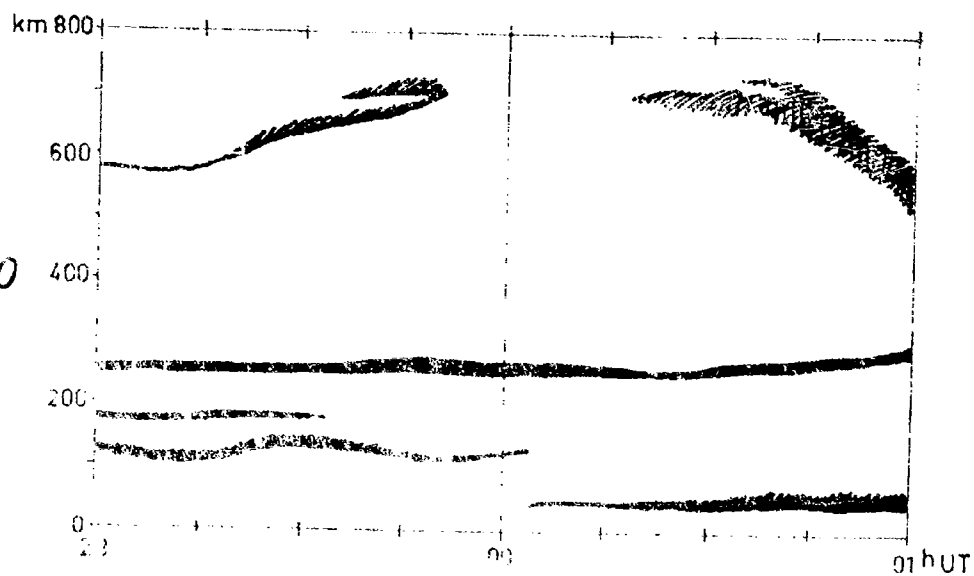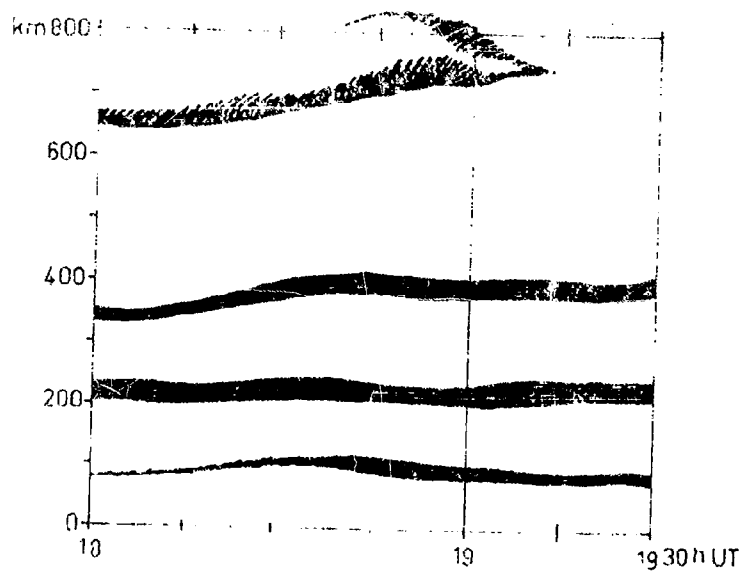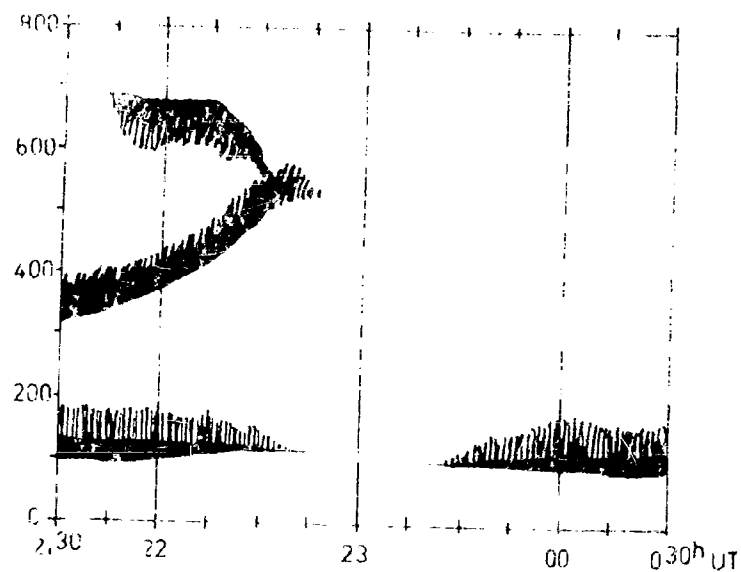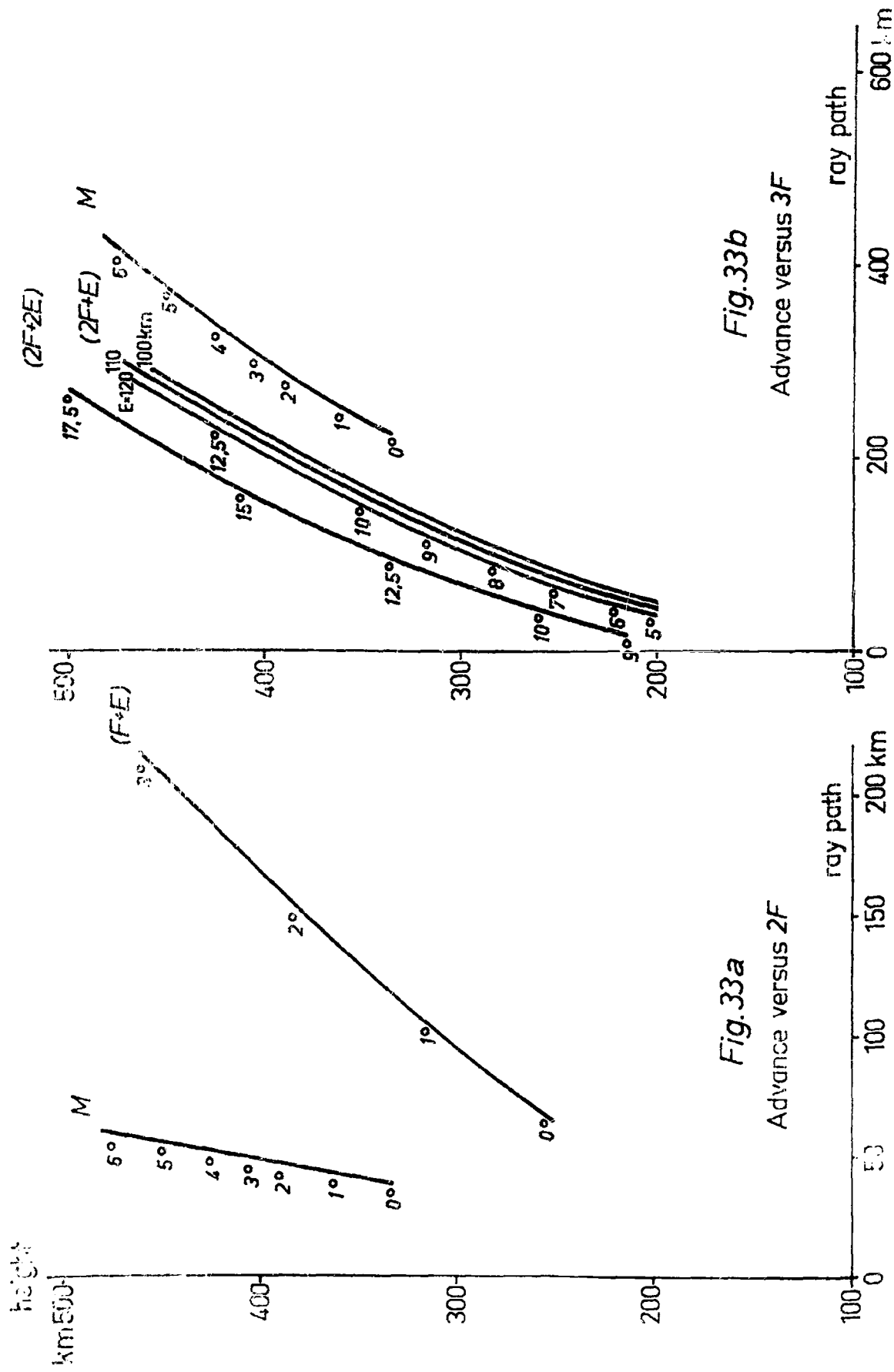
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date : 30 November 1960
No. pages and illus.: 26 pages and 33 figures
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